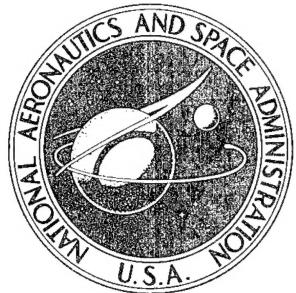


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NOLIN - A NONLINEAR
LAMINATE ANALYSIS PROGRAM

John J. Kibler

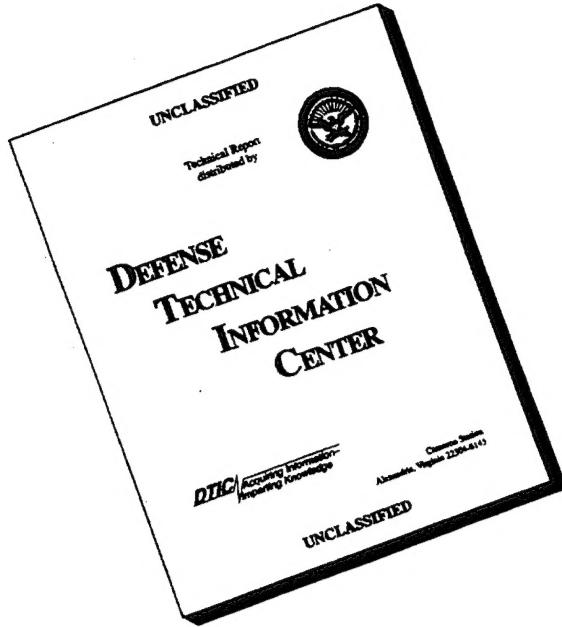
Prepared by
MATERIALS SCIENCES CORPORATION
Blue Bell, Penn. 19422
for Langley Research Center

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NOLIN
A NONLINEAR LAMINATE ANALYSIS PROGRAM

by
John J. Kibler

SUMMARY

A nonlinear, plane-stress, laminate analysis program, NOLIN, has been developed which accounts for laminae nonlinearity under inplane shear and transverse extensional stress. The program determines the nonlinear stress-strain behavior of symmetric laminates subjected to any combination of inplane shear and biaxial extensional loadings. The program has the ability to treat different stress-strain behavior in tension and compression, and predicts laminate failure using any or all of maximum stress, maximum strain, and quadratic interaction failure criteria.

A second program, UNI, has been developed which computes elastic constants and thermal coefficients of expansion for laminae, from constituent properties, to aid in compiling input for the NOLIN program. Laminae properties can be computed for isotropic or transversely isotropic fibers in an isotropic matrix. In addition, the nonlinear inplane shear stress-strain curves are computed for the laminae by computing the Ramberg-Osgood shear stress parameter.

This document provides brief descriptions of both programs, a description of the flow of information through the NOLIN program, and detailed descriptions of the input required for each program. Sections are provided with sample problems and sample program output, along with complete listings of each program.

1. NOLIN Program Description

1.1 Introduction

The NOLIN program codifies a nonlinear, plane-stress, laminate analysis wherein the nonlinear behavior of the laminae under inplane shear and transverse extensional stresses are taken into account. Both the underlying analytical development and the computer program are sufficiently general to enable the user to study the nonlinear behavior of a symmetric laminate subjected to any combination of in-plane shear and biaxial extensional loadings. Contained in this document are a detailed description of the input required to use the NOLIN program, as well as a description of the theoretical developments upon which the program is based. For a complete theoretical description the reader is referred to Ref. 1.

In unidirectional, fiber-reinforced laminae, the transverse extensional and, particularly, the inplane shear stress-strain relationships cannot be accurately characterized as linear. The NOLIN program allows for nonlinear representations by permitting these stress-strain relationships to take the form of Ramberg-Osgood nonlinear relationships. The introduction of these nonlinear, Ramberg-Osgood type constitutive relationships into a laminate analysis then leads to a set of nonlinear equations involving the laminae stress components as unknowns. The program then solves this set of equations by means of a generalized, Newton-Raphson procedure to give the laminae stresses and strains corresponding to the applied boundary stresses.

The theoretical development for this nonlinear, laminate analysis incorporates total deformation theory with Ramberg-Osgood type stress-strain characterizations to formulate the governing nonlinear equations. At the outset the compliance tensor is assumed to be the sum of two tensors, the components of one are the usual components associated with linear,

orthotropic, plane-stress elasticity theory, while the second tensor contains the nonlinear elements. By assuming a quadratic interaction of the stress components, and requiring the constitutive relationship to reduce to the relationships for the uniaxial stress cases of inplane shear and transverse extension, the elements of the nonlinear compliance tensor are explicitly determined.

Having the nonlinear laminae constitutive relations, the usual methods of laminate theory are then utilized to obtain the governing, nonlinear equations for the laminate. As in linear, laminate theory, the strains of the individual laminae are first rotated to a common set of laminate axis, and the laminate compatibility relations requiring the corresponding strains of the individual laminae to be equal are then employed. In addition, equilibrium at the laminate boundaries is envoked. In this way the required number of equations involving the unknown laminae stresses are formulated.

The program solution procedure for the set of nonlinear equations involving the laminae stress components is a Newton-Raphson technique generalized to accomodate systems of equations. The starting point for the solution procedure is taken as the solution of the associated, linear laminate problem, where the associated linear problem is obtained by ignoring all nonlinear terms.

Incorporated into the program are three different failure criteria, maximum stress, maximum strain and a quadratic interaction criteria. Any or all of these may be employed by the program user. Unfortunately, the nonlinear aspects of this program preclude the generation of strength envelopes since linear extrapolation is not valid here. Instead a sequence of combined loadings may be run.

The governing equations are formulated so that the three stress components in each lamina are the unknowns. Thus, for an N -layered laminate, the problem is formulated in terms of $3N$ unknowns. To obtain solutions, $3N$ equations are then required, and these equations consist of three equilibrium equations and $3(N-1)$ compatibility equations satisfying strain compatibility between adjacent laminae. The three equations of equilibrium for a laminate under a combined state of stress are,

$$\begin{aligned} \sum_{k=1}^N \sigma_{11}^{(k)} t_k &= N_{11} \\ \sum_{k=1}^N \sigma_{22}^{(k)} t_k &= N_{22} \\ \sum_{k=1}^N \sigma_{12}^{(k)} t_k &= N_{12} \end{aligned} \quad (6)$$

Where N_{11} , N_{22} and N_{12} are the applied stress resultants, t_k the thickness of the k th lamina, and subscripts 1 and 2 denote the laminate axes. The $3(N-1)$ equations of strain compatibility are,

$$\begin{aligned} \epsilon_{11}^{(k)} &= \epsilon_{11}^{(k-1)} \\ \epsilon_{22}^{(k)} &= \epsilon_{22}^{(k-1)} \\ \epsilon_{12}^{(k)} &= \epsilon_{12}^{(k-1)} \end{aligned} \quad (7)$$

$k = 2, 3, \dots, N$

Equations (6) and (7) are the $3N$ equations required for the solution of the nonlinear laminate problem. When the stress-strain relations given by equations (2), (4) and (5) are transformed to the laminate reference axes and substituted into equations (7), the governing equations can be expressed

in functional form as,

$$F_k (\sigma_1, \sigma_2, \dots, \sigma_1^2, \dots) = 0 \quad (8)$$

$$k = 1, 2, \dots, 3N$$

1.3 Method of Solution

Solutions of equations (8) for the $3N$ stress components are obtained by employing a Newton-Raphson iterative scheme. The functions F_k are first expanded in Taylor series about an approximate set of initial stresses, σ_j° . Considering only the first order terms of these series,

$$F_k = F_k^\circ + \left(\frac{\partial F_k}{\partial \sigma_j} \right) \Big|_{\sigma_j^\circ} \cdot \Delta \sigma_j \quad (9)$$

$$j, k = 1, 2, \dots, 3N$$

By writing,

$$\Delta \sigma_j = \sigma_j - \sigma_j^\circ$$

where σ_j are the solution values, equations (9) can be rewritten to give

$$\sigma_j = \sigma_j^\circ - \left(\frac{\partial F_k}{\partial \sigma_j} \right) \cdot F_k^\circ \quad (10)$$

$$j, k = 1, 2, \dots, 3N$$

For clarity, the notation in equations (10) is, in expanded form,

$$\sigma_j = \begin{bmatrix} \sigma_1 \\ \sigma_2 \\ \vdots \\ \vdots \\ \sigma_N \end{bmatrix} \quad (11)$$

$$\sigma_j^o = \begin{bmatrix} \sigma_1^o \\ \sigma_2^o \\ \vdots \\ \vdots \\ \sigma_N^o \end{bmatrix} \quad (12)$$

$$F_k^o = \begin{bmatrix} F_1^o \\ F_2^o \\ \vdots \\ \vdots \\ F_N^o \end{bmatrix} \quad (13)$$

and,

$$\left(\frac{\partial F_k}{\partial \sigma_j} \right) \sigma_j^o = \left| \begin{array}{ccc|c} \frac{\partial F_1}{\partial \sigma_1} & \frac{\partial F_1}{\partial \sigma_2} & \cdots & \\ \frac{\partial F_2}{\partial \sigma_1} & \frac{\partial F_2}{\partial \sigma_2} & \cdots & \\ \vdots & \vdots & & \\ \vdots & \vdots & & \end{array} \right| \quad \sigma_j = \sigma_j^o \quad (14)$$

The solution for σ_j in equation (10) may be taken as the approximate, initial stress values for the next iteration step, and this process repeated until a result is obtained within some desired accuracy. After the stresses are obtained and transformed to the laminae natural axes, the corresponding laminae strains are determined from equations (1), (2) and (5).

1.4 Computer Program

The flow chart for the computer program is shown in Fig. 1. The major sections of the program are the formation of the governing equations, the Newton-Raphson solution procedure and the failure checks.

Using the computer program notation, the governing equations take the form,

$$[A] \cdot \bar{S}G + \bar{B} = \bar{SGO} \quad (15)$$

Where $\bar{S}G$ and \bar{SGO} are the stress solution vector and the applied stress vector, respectively. A is a matrix of constant elements which are the coefficients of the linear terms in the solution, and \bar{B} is a vector containing the nonlinear terms in the solution. The set of equations (15) are equivalent to equations (8). If in equation (15) the vector \bar{B} is set to zero, the resulting equation

$$[A] \cdot \bar{S}G = \bar{SGO} \quad (16)$$

is the linear laminate solution. The stress vector, $\bar{S}G$, as determined from equation (16) is taken as the initial approximation for the stress vector in the Newton-Raphson procedure.

For the Newton-Raphson procedure it is necessary to formulate the derivative of $([A] \cdot \bar{S}G + \bar{B})$ in equation (15) with respect to σ_j as well as the vector

$$\bar{DC} = ([A] \cdot \bar{SGO} + \bar{B} - \bar{SG}) \quad (17)$$

The vector \bar{DC} corresponds to the vector \bar{F}_f^o in equation (10), and an explicit evaluation of \bar{DC} is obtained by using the current, approximate value for the solution stress vector, $\bar{S}G$. The derivative of $([A] \cdot \bar{S}G + \bar{B})$ is designated \bar{DB} in the computer program, and is equivalent to the matrix $(\partial F_k / \partial \sigma_j) \sigma_j^o$ in equation (10). An explicit evaluation of \bar{DB} is also obtained by using the current, approximate value for the solution stress vector, $\bar{S}G$.

In the program, the external loading is applied in increments. The approximate solution stress vector for the first load increment and the first Newton-Raphson iteration is determined from equation (16). For the second and third load increments, the approximate solution stress vectors for the first iteration are taken as the final solution stress vectors from the previous increments. Solutions for subsequent load increments are initiated by the following algorithm:

$$(SG_i + 1)_{\text{INITIAL}} = (SG_i)_{\text{FINAL}} * (\text{FACTOR}) \quad (18)$$

$$(\text{FACTOR}) = \frac{i(i-2)}{(i-1)^2} \frac{(SG_i)_{\text{FINAL}} - (SG_{i-1})_{\text{FINAL}}}{(SG_i)_{\text{FINAL}}}$$

The convergence and divergence criteria employed in the program are contained in the following expressions:

$$\begin{aligned} |(SG_{i+1} - SG_i)/SG_i| &\leq \epsilon \\ |(SG_{i+1} - SG_i)/SG_i| &< \lambda \end{aligned} \quad (19)$$

Where SG_i and SG_{i+1} are the solution vectors obtained from the i^{th} and $i+1^{\text{th}}$ iterations. Usually values of 10^{-3} and 10^{+4} are taken for ϵ and λ , respectively. However, the other values may be input as data to the program. In addition, the maximum number of iterations to be allowed is input as data. Ten iterations have been found to be sufficient for most problems.

The program contains three failure criteria, maximum strain, maximum stress, and a quadratic interaction criteria. After a solution is obtained for each load increment any or all of these failure criterias may be applied to check for laminae failure.

The maximum stress and maximum strain failure criteria check, respectively, the laminae stress or strain values in

the fiber, and transverse fiber directions against the material allowables. These allowables are input to the program as data. The quadratic criteria is given by

$$\begin{aligned} A_{11} \sigma_{LL}^2 + A_{22} \sigma_{TT}^2 + A_{44} \sigma_{LT}^2 \\ + A_{12} \sigma_{LL} \sigma_{TT} + B_1 \sigma_{LL} + B_2 \sigma_{TT} = 1 \end{aligned} \quad (20)$$

where the coefficients are functions of the allowable stress

$$\begin{aligned} A_{11} &= \frac{1}{F_L^T F_L^C} & B_{11} &= \frac{1}{F_L^T} - \frac{1}{F_L^C} \\ A_{22} &= \frac{1}{F_T^T F_T^C} & B_{22} &= \frac{1}{F_T^T} - \frac{1}{F_T^C} \\ A_{44} &= \frac{1}{(F_S^S)^2} \end{aligned} \quad (21)$$

F_L^t and F_L^c are the allowable tension and compression stresses in the longitudinal direction, F_T^t and F_T^c are the allowable tension and compression stresses in the transverse direction, and F_S^S is the allowable shear stress. The coefficient A_{12} is input as data to the program, or a default null value is used.

If a failure criteria is satisfied at the end of a load increment, the program determines the failure load through linear interpolation. If all failure criteria are being checked, and not all indicate failure during the same load increment, the program continues loading until all criteria indicate failure.

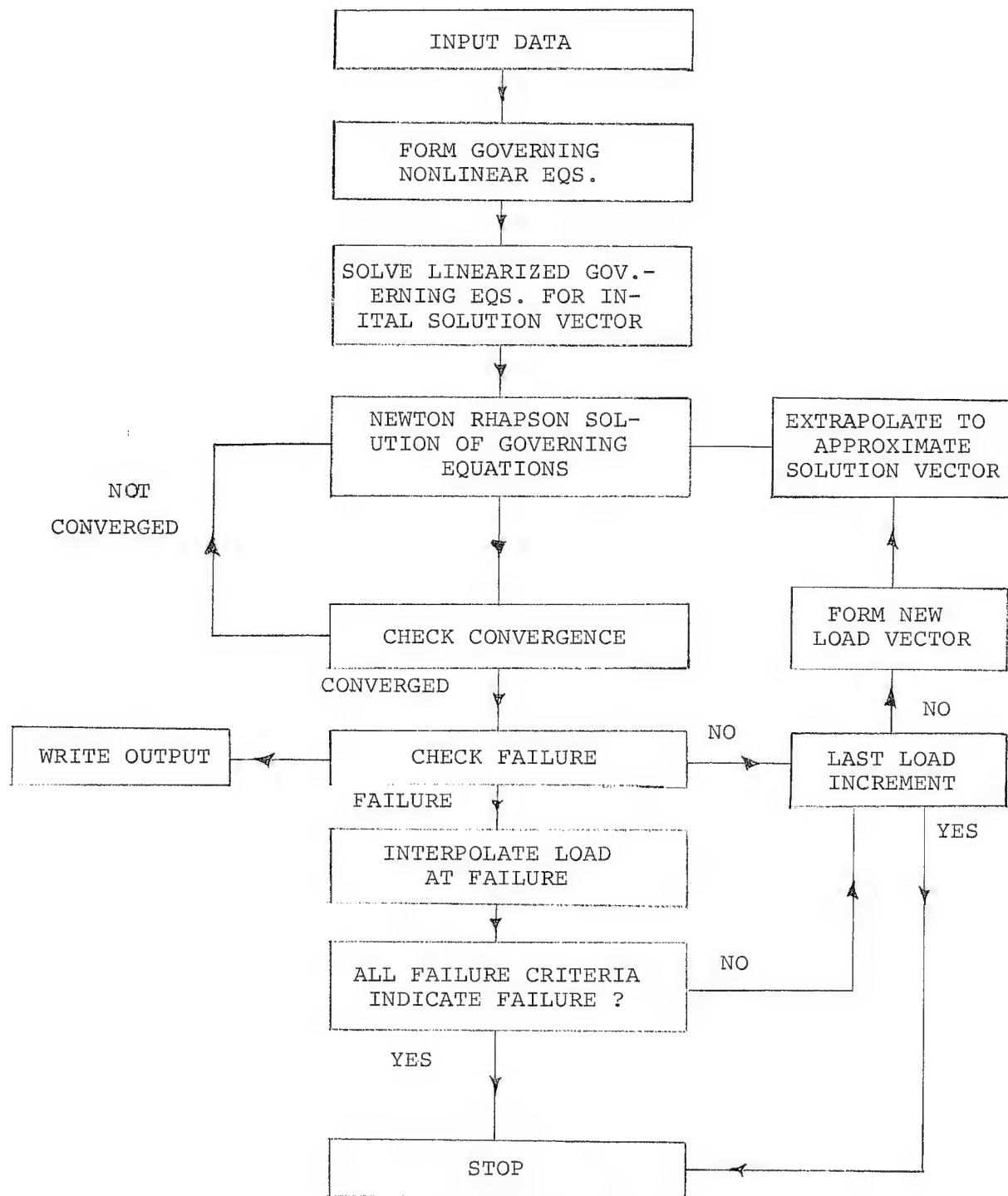


Figure 1 - Solution flow Chart

2. NOLIN PROGRAM USERS GUIDE

2.1 Program Description

This section describes the input data requirements for NOLIN (version 2 mod 2). Input procedures have been streamlined wherever possible by using one NAMELIST statement, hence eliminating any input under format control.

The input flow diagram and input description provide all information necessary to specify input data sets capable of exercising all program options.

2.2 Input Description

The initial data required is a message of five cards of alphanumeric descriptive information describing the problem being solved and printed as a title on the output. These five cards may be left blank, but must be included ahead of the first NAMELIST deck in the data. This descriptive message is read only once at the beginning of the program execution. The multiple case feature of running successive computations is accomplished by supplying multiple NAMELIST data sets with the changed variables indicated.

The following is a description of the input variables required for execution of the program. Where appropriate, default or suggested values are indicated. The following data are supplied through NAMELIST "DATA":

Program Option Parameters

IOPT:	Ramberg-Osgood parameter sentinel. IOPT=1: Input R-O parameter directly. IOPT=2: Determine parameters from stress-strain curve-fit routine.
COPT:	Curve-fit sentinel, (exercised if IOPT=2) COPT=1: Same stress-strain data for each layer. COPT=2: Different sets of data for each layer.

EOPT: Exponent option, (exercised if IOPT=2)
EOPT=1: Determine exponents from curve-fit routine.
EOPT=2: Input exponents to curve-fit routine.

Solution Accuracy Parameters

KSGM: No. of load increments, maximum = 50 increments.
SMLT: Load increment multiple, maximum number of Newton-Raphson iterations, default is 100.
EPS: Convergence criteria for Newton-Raphson analysis, default value is 10^{-3} .
UPBD: Divergence criteria during Newton-Raphson analysis, default value is 20000.
INMT: Incrementation estimate method, default value is 2.

Layer Description

NLAY: Number of laminate layers (max. is 20).
THICK(LAY) : Thickness of each layer.
THETA(LAY) : Orientation of each layer in degrees.
MATYPE(LAY) : Material kind of each layer (maximum number of different materials is 20).

Material Description

E11 (MATYPE) : Lamina longitudinal modulus.
E22 " Lamina transverse modulus.
G12 " Lamina shear modulus.
V12 " Lamina major Poisson's ratio.
S11T " Lamina longitudinal tensile strength.
S11C " Lamina longitudinal compressive strength.
S22T " Lamina transverse tensile strength.

S22C (MATTYPE) :	Lamina transverse compressive strength.
S12 "	Lamina in-plane shear strength.
EP11T "	Lamina longitudinal tensile strain.
EP11C "	Lamina longitudinal compressive strain.
EP22T "	Lamina transverse tensile strain.
EP22C "	Lamina transverse compressive strain.
GAMA "	Lamina in-plane shear strain.
A12 "	Lamina interaction term for quadratic interaction criteria - default value is 0.0.
STY "	Ramberg-Osgood tension constant
SCY "	Ramberg-Osgood compression constant
TY "	Ramberg-Osgood shear constant.
XM "	Ramberg-Osgood shear exponent (default value is 3.0).
XN "	Ramberg-Osgood tension exponent (default value is 3.0).

Stress-Strain Data (input in IOPT=2)

IPTS:	Number of stress-strain data points.
SIG11(I,MATTYPE) :	IPTS values of longitudinal lamina stresses for each material type.
SIG22 "	IPTS values to transverse lamina stresses for each material type.
SIG12 "	IPTS values of in-plane shear stresses for each material type.
EPS11 "	IPTS values of longitudinal lamina strains for each material type.
EPS22 "	IPTS values of transverse lamina strains for each material type.
EPS12 "	IPTS values of in-plane shear strain for each material type.

Applied Loading and Failure Criteria

S011: Initial axial stress applied to laminate.
S022: Initial transverse stress applied to
laminate.
S012: Initial shear stress applied to laminate.
IFCN: Failure criteria sentinel
 IFCN=1: ultimate stress
 IFCN=2: ultimate strain
 IFCN=3: quadratic interaction
 IFCN=4: all failure criteria
STIFF: Ratio of final to initial laminate
stiffness which constitutes failure
due to stiffness reduction, default
value is 0.10.

3. UNI PROGRAM

3.1 Description

Program UNI computes the elastic properties, thermal expansion coefficients and the Ramberg-Osgood shear stress parameter for the unidirectional fiber bundle or the lamina. The fiber may be isotropic or transversely isotropic and the matrix is isotropic. The effective elastic properties of the composite are calculated from the composite cylinder assemblage model proposed by Hashin and Rosen [2] and the thermal expansion coefficients from the analytical results of Ref. [3]. The program also calculates the Ramberg-Osgood shear stress parameter of the matrix as outlined in Ref. [1].

The UNI program takes constituent properties as input and computes laminae properties as output. The output properties provide all the information required as input to the NOLIN program. The program accepts families of fiber and matrix materials such that an array of laminae properties can be generated. This feature can be especially useful for sensitivity analyses. All input to UNI is accomplished through a single NAMELIST statement "UNID".

3.2 Input Description

The following describes the variables required for the execution of UNI through NAMELIST "UNID".

Program Control Variables

NF:	No. of fibers, max. is 20.
NM:	No. of matrices, max. is 20.
NVM:	No. of matrix vol. fractions, max. is 20.

Matrix Properties, J=1, NM

EM(J) : Young's modulus for Jth matrix.
RHOM(J) : Density of Jth matrix.
ANUM(J) : Poisson ratio for Jth matrix.
ALPM(J) : Coef. of thermal expansion for Jth matrix required only if ISTS=1.
ROMS(J) : Shear stress Ramberg-Osgood parameter for Jth matrix required only if NONLIN = 1.

Isotropic Fiber Properties, J=1, NF

The following variables are required when ISOT=1:

EF(J) : Young's modulus for Jth fiber.
ANUF(J) : Poisson ratio for Jth fiber.
RHOF(J) : Density of Jth fiber.
ALPF(J) : Coef. of thermal expansion for Jth fiber (required only if ISTS=1).

Transversely Isotropic Fiber Properties, J=1 NF

The following variables are required when ISOT=2:

EFA(J) : Axial Young's modulus for Jth fiber.
EFT(J) : Transverse Young's modulus for Jth fiber.
ANUFA(J) : Axial Poisson ratio for Jth fiber.
GFA(J) : Axial shear modulus for Jth fiber.
ANUFT(J) : Transverse Poisson ratio for Jth fiber.
ALPF(J) : Axial thermal expan. coef. for Jth fiber (required only if ISTS=1).
ALPFT(J) : Transverse thermal exp. coef. for Jth fiber.
(required only if ISTS=1).

Laminae Volume Fractions, J=1, NVM

VM(J) : Jth volume fraction of matrix material.

The UNI program computes laminae properties for all combinations of fibers, matrix materials, and volume fractions which are supplied as input. That is, there are a total of NF x NM x NVM materials formed from the input. Within a given run the total number of materials (NFxNMxNVM) must be less than 200.

The following is a description of the properties computed by UNI and printed as output:

Calculated Thermo-Elastic Constituent Parameters

GFT(J) : Transverse shear modulus for Jth fiber.
GF(J) : Shear modulus for Jth fiber.
GM(J) : Shear modulus for Jth matrix.
AKF(J) : Plane strain bulk modulus for Jth fiber.
AKM(J) : Plane strain bulk modulus for Jth matrix.

Effective Thermo-Elastic Parameters

AKTS(J) : Effective trans. bulk modulus for Jth material.
EAS(J) : Effective axial Young's modulus for Jth material.
ETS(J) : Effective trans. Young's modulus for Jth material.
ANUAS(J) : Eff. Poisson ratio (unidirectional axial stress) for Jth material.
ANUTS(J) : Eff. Poisson ratio (in transverse plane) for Jth material.
GAS(J) : Eff. shear modulus (in fiber planes) for Jth material.
GTS(J) : Eff. shear modulus (in trans. planes) for Jth material.

ALPAS (J) : Eff. (fiber direction) thermal exp.
coef. for Jth material.

ALPTS (J) : Eff. (trans. direction) thermal exp. coef.
for Jth material.

RHOS (J) : Bulk density for Jth material.

ROCOMP (J) : Ramberg-Osgood shear stress parameter
for Jth material.

4. SAMPLE PROBLEMS

The purpose of this section is to present several sample problems which illustrate the capabilities of both the UNI and the NOLIN programs. Both the program input and output are listed at the end of this section to aid in understanding the program.

4.1 UNI - Sample Problems

4.1.1 Laminae properties for Thornel 50 fibers in two carbon matrices have been determined. The transversely isotropic fiber option has been used to model the Thornel 50 fibers, and a Ramberg-Osgood shear stress parameter is included for the two matrix materials.

The input data and the resulting output data are given in sections 4.1.2 and 4.1.3. Note that the constituent properties are mirrored in the program output along with the required computed constituent properties. The effective thermoelastic properties for the 1-D laminae are printed on the second page of output. Units are consistent throughout the program such that the units need only be consistent for the constituent properties, in this case properties were input as MN/M².

The second sample problem combines KEVLAR-49 fibers with a range of matrix properties to obtain the 1-D composite properties. A list of input data for this case and the corresponding program output are shown in sections 4.1.2 and 4.1.3. It is interesting to note that an order of magnitude change in matrix modulus results in a factor of five change in transverse modulus and transverse shear modulus.

4.1.2 UNI SAMPLE PROBLEMS - INPUT CARDS

C UNI DATA

```
$DATAUNI  
NF=1,      NMF=2,      NV=2,        
EFA(1)=3.8E+03,    EFT(1)=7.E+03+0.5,    GFA(1)=1.E+04,  
ANUFA(1)=0.,       ANUFT(1)=0.,         
RHOF(1)=1.,         VM(1)=0.,  
EM(1)=1.7E+14,    3.0E+04,  
ANIU(1)=2*0.2,     RHOF(1)=2*1.,  
VM(1)=0.4, 0.6,  
ROMS(1)=2*3.0,  
ALPF(1)=5.E-07,  
ALPFT(1)=5.0E-05,  
ALPM(1)=2*1.4E-16*  
$DATAUNI  
NF=1,      NMF=10,      NV=10,        
EFA(1)=1.3E+03,    EFT(1)=1.2,      RHOF(1)=1.,  
EFT(1)=9.2E+03,    ALPFT(1)=0.2,    GFA(1)=1.7E+03,  
EM(1)=1.E+03, 1.E+03, 1.5E+03, 2.E+03, 1.E+03, 3.E+03,  
3.5E+03, 4.E+03, 4.E+03, 5.E+03,  
ANIU(1)=1.*1.2,    RHOF(1)=10*1.,  
VM(1)=0.4,  
ALPF(1)=-6.1E-17,  ALPFT(1)=3.88E-06,  
ALPM(1)=1.*1.32E-14*
```

A 1 3 INIT SAMPLE PROBE FM OUT PHT

1

FIBER NO.	$F(F)$	$N_U(F)$	$S(F)$	$\kappa(F)$	$RHO(F)$	$ALPHA(F)$
1	3.6000E+05 7230.0	10000 10000	13800 286.4	4018.4 4018.4	1.0000 1.0000	5.0000E- 3.6000E-
1	5.0000E+05 7230.0	10000 10000	13800 286.4	4018.4 4018.4	1.0000 1.0000	5.0000E- 3.6000E-
MATRIX NO.	$E(\cdot)$	$N_U(M)$	$S(M)$	$\kappa(M)$	$RHO(M)$	$ALPHA(M)$

1	17000	.20000	7033.3	11606	1,0000	1,4000E+06
2	34000	.20000	14167	23611	1,0000	1,4000E+06

卷之三

EFFECTIVE THERMODYNAMIC PARAMETERS

F	M	MATERIAL	V(%)	E(A)*	E(T)*	NJ(A)*	NJ(T)*	K(T)*	G(A)*	RHO*	ALPHA(A)*	ALPHA(T)*
1	1	1	.40000	2.34833E+15 1n393	.15351 .16120	1.6471 4475.1	6210.6 1.00000	5.23229E-87 2.51547E-86	5.52941E-87 2.13356E-86	6.01723E-87 1.94690E-86	1.2234 1.0000	
				R=0 PARAMETER =	3.11794E+011							
1	1	2	.60000	1.622270E+15 123n2	.17215 .1R709	9175.0 5211.3	76667.0 1.00000					
				R=0 PARAMETER =	2.96561F+011							
1	2	3	.40000	2.41649E+15 14403	.16535 .17125	1.7946 6196.8	8778.4 1.00000	5.46548E-87 2.12723E-86	5.46548E-87 2.12723E-86	6.01723E-87 1.94690E-86	1.2234 1.0000	
				R=3 PARAMETER =	3.11794F+011							
1	2	4	.60000	1.72441E+15 19563	.18093 .19299	14019 199.3						
						2.96561E+011						

EFFECTIVE THERMO-ELASTIC PARAMETERS

F	H	MATERIAL	V(M)	F(A)* F(T)*	Nu(A)* Nu(T)*	G(A)* G(T)*	K(T)* RHO*	ALPHA(A)* ALPHA(T)*
1	1	1	.40000	78200 1596.5	.20000 .21564	5.135 656.64	1.019.8 1.00000	-5.72890E-07 6.33022E-06
1	2	2	.40000	78400 2603.9	.20000 .21802	749.63 1.151.0	1.799.4 1.00000	-5.35969E-07 6.42491E-06
1	3	3	.40000	78600 3760.0	.20000 .24920	903.44 1542.0	2449.6 1.00000	-4.99237E-07 6.51767E-06
1	4	4	.40000	78800 4543.4	.20000 .24973	1020.12 1.362.4	2928.7 1.00000	-4.62690E-07 6.60856E-06
1	5	5	.40000	79000 5202.6	.20000 .21990	1116.8 2132.4	3357.3 1.00000	-4.26329E-07 6.69761E-06
1	6	6	.40000	79200 5769.5	.20000 .21985	1201.4 2.364.8	3725.5 1.00000	-3.90152E-07 6.78490E-06
1	7	7	.40000	79400 6265.5	.20000 .21969	1278.2 2.568.5	4047.5 1.00000	-3.54156E-07 6.87046E-06
1	8	8	.40000	79600 6766.1	.20000 .21945	1349.8 2.749.6	4333.1 1.00000	-3.18342E-07 6.95435E-06
1	9	9	.40000	79800 71n2.3	.20000 .21917	1417.6 2.912.8	4589.8 1.00000	-2.62707E-07 7.03662E-06
1	10	10	.40000	80000 7462.7	.20000 .21887	1482.7 3.061.3	4822.9 1.00000	-2.47250E-07 7.11730E-06

4.2 NOLIN Sample Problems

4.2.1 The sample problems for the NOLIN program have been chosen to exercise several options of the program. Graphite/Epoxy and Boron/Aluminum laminates have been modeled, employing material properties derived from the Air Force Composites Design Guide.

The initial problem is a $\pm 30^\circ$ Boron/Aluminum laminate under uniaxial tensile loading. Ramberg-Osgood parameters were input, with exponents set equal to 3.0, and a maximum strain failure criteria was employed. The input data and the program output follow in sections 4.2.2 and 4.2.3 respectively. A graph of the axial stress-strain curve for the laminate is given in Figure 2. Note that the laminate exhibits a non-linear stress-strain behavior from loading onset to failure.

The second sample nonlinear laminate analysis problem is a 0, ± 45 Graphite/Epoxy laminate under combined tension and shear loading. In this case the Ramberg-Osgood parameters were determined by the curve-fit routine from uniaxial stress-strain data supplied as input. The input data and program output listing are given in sections 4.2.2 and 4.2.3 respectively. Output of the program is plotted in the form of axial stress versus axial strain for this case in Figure 3.

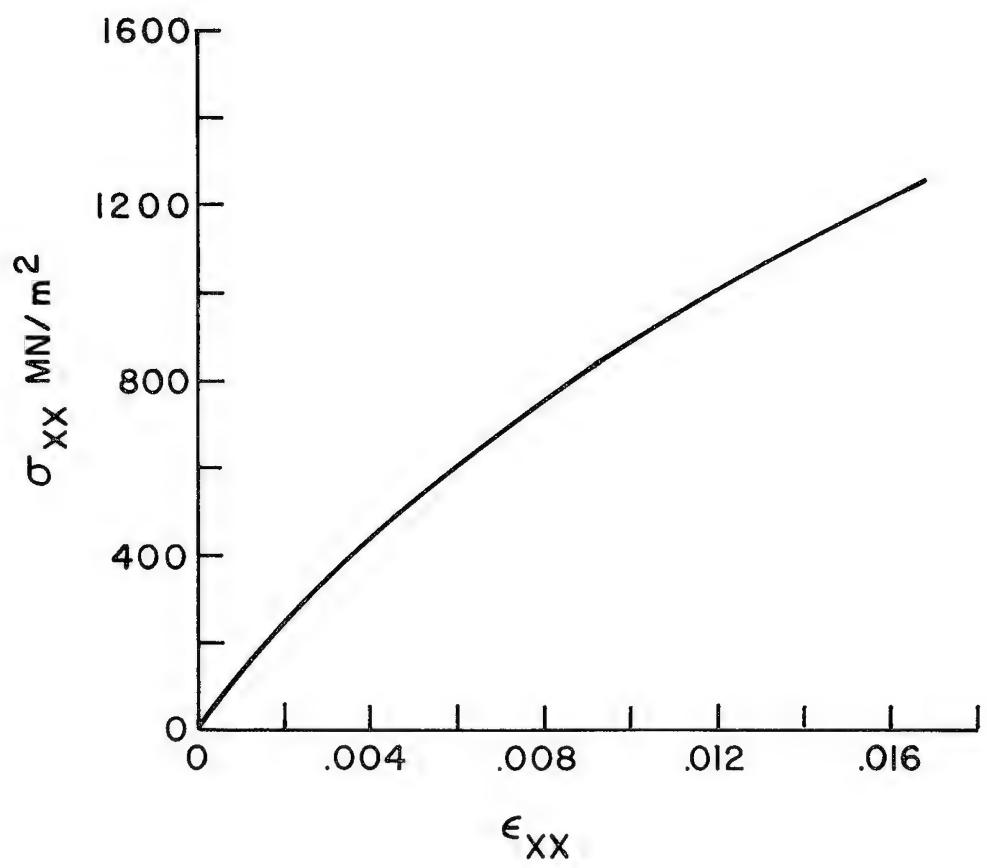


Figure 2 - +30° Boron/Aluminum Laminate - Axial Stress-Strain Behavior.

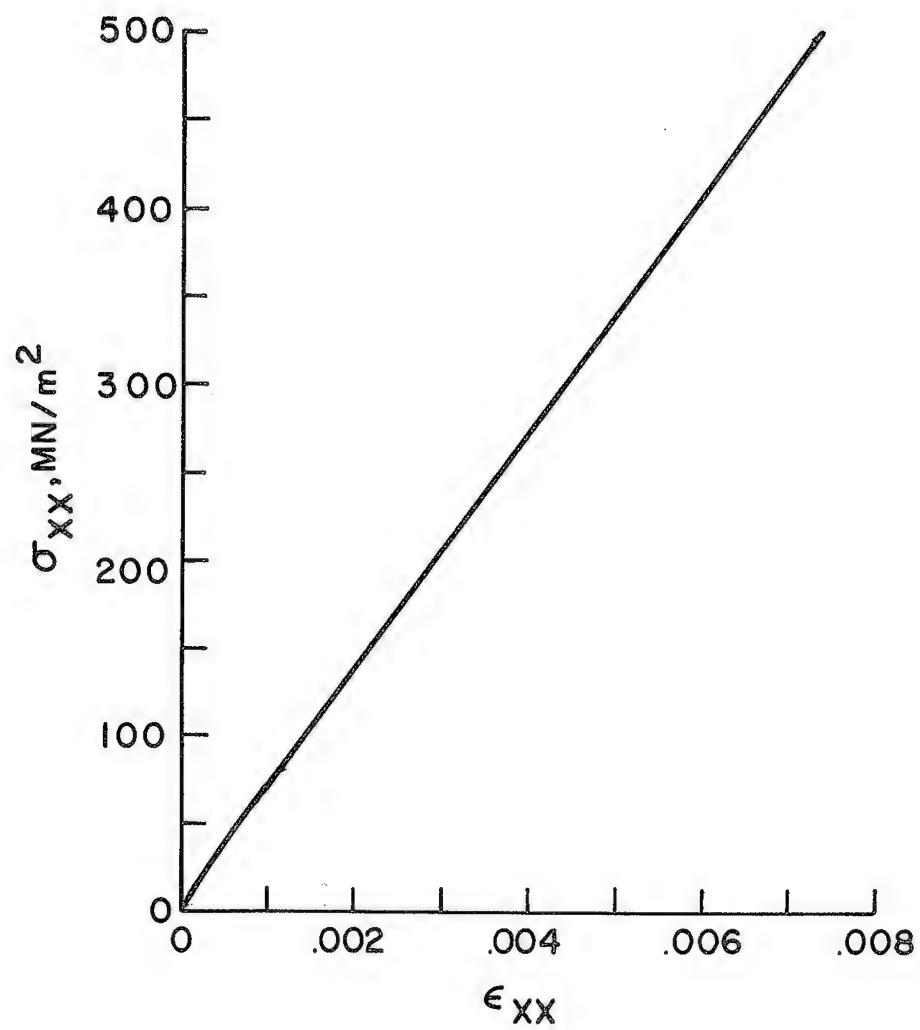


Figure 3 - Axial Stress-Strain Response of [0+45] Graphite-Epoxy Laminate under Axial and Shear Loading.

4.2.2 NOLIN SAMPLE PROBLEM INPUT CARDS

C NOLIN DATA

```
*  
* NOLIN SAMPLE PROBLEMS  
*  
* 1, 0,+45,-45 LAMINATE, FULL R=0 PARAM CURVE-FIT, ALL FAIL CRIT,  
* 2, +30,-30 LAMINATE, R=0 PARAM INPUT, STRAIN FAIL CRIT.  
$DATA  
NLAY=3,  
E11(1)=3*1,982E+05,  
E22(1)=3*1,900E+04;  
V12(1)=3*0,255E+00;  
G12(1)=3*5,770E+03;  
THICK(1)=0,25,0,5,0,25,  
THETA(1)=45,,0,0,-45,,  
IOPt=2,EOPt=1,COPt=1,  
IPtS=10,  
SIG11(1,1)=6,89E+00,13,78E+00,20,67E+00,27,56E+00,34,45E+00,41,34E+00,  
48,23E+00,55,12E+00,62,01E+00,68,90E+00,  
EPS11(1,1)=1,1E-03,2,6E-03,4,E-03,5,7E-03,7,6E-03,1,E-02,1,31E-02,  
1,65E-02,2745E-02,2,84E-02,  
SIG22(1,1)=6,89E+00,13,78E+00,20,67E+00,27,56E+00,34,45E+00,41,34E+00,  
48,23E+00,55,12E+00,62,01E+00,68,90E+00,  
EPS22(1,1)=1,1E-03,2,6E-03,4,E-03,5,7E-03,7,6E-03,1,E-02,1,31E-02,  
1,65E-02,2745E-02,2,84E-02,  
SIG12(1,1)=6,89E+00,13,78E+00,20,67E+00,27,56E+00,34,45E+00,41,34E+00,
```

NOLIN SAMPLE INPUT CARDS CONT.

```
48,23E+00,55,12E+00,62,01E+00,68,90E+00,
EPS12(1,1)=2,2E-03,5,2E-03,8,E-03,11,4E-03,15,2E-03,2,E-02,2,62E-02,
3,30E-02,4,30E-02,5,68E-02,
S011=+5,0E+00,S022=-2,5E+00,S012=0.0,
IFCN=4,IPRINT=1,
MATYPE(1)=1,1,1,
S11T(1)=1,32E03,S22T(1)=7,16E+01,S12(1)=1,05E+02,EP11T(1)=6,68E-03,
EP22T(1)=3,77E-03,GAMA(1)=1,827E+02,S11C(1)=2,43E+03,S22C(1)=2,75E+02,
EP11C(1)=1,227E-02,EP22C(1)=1,45E-02,
STIFF=0,100,
A12(1)= 3*-2,8623E+06,
KSGM=50,SMLT=3,0,IT=10,TNMT=2$,
$DATA
NLAY=2,
E11(1)=2*2,20E+05,
E22(1)=2*1,24E+05,
V12(1)=2*0,01E+00,
G12(1)=2*2,60E+04,
THICK(1)=2*0,50,
THETA(1)=30.0,-30.0,
IOPR=1,
STY(1)=2*1109,E+00,
SCY(1)=2*1467,E+00,
TY(1)=2*93,0E+00,
XM=3,00,XN=3,00,
S011=50.,
S022=0.,
S012=0.,
IFCN=2,
S11T(1)=1100,0,S22T(1)=103,0,S12(1)=93,0,EP11T(1)=0,7E-02,
EP22T(1)=2,0E-02,GAMA(1)=3,0E-02,S11C(1)=1480,0,S22C(1)=160,,
EP11C(1)=0,7E-02,EP22C(1)=0,02,
STIFF=0,100,
KSGM=48,SMLT=4$
```

4.2.3 NOLIN SAMPLE
OUTPUT

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NONLINEAR
THERMOELASTIC ANALYSIS
OF
FIBROUS COMPOSITES
AND
NON-HOMOGENEOUS LAMINATES

* * * * *

* VERSION 2 MOD 3 (MAY 74)

* DATE

* PROGRAM IDENTIFICATION

* * NOLIN SAMPLE PROBLEMS
* * VERS 2 MOD 3
* * 1. 0+45+45 LAMINATE. FULL R=0 PARAM CURVE-FIT. ALL FAIL CRIT.
* * 2. +30+30 LAMINATE. R=0 PARAM INPUT. STRAIN FAIL CRIT.

LAMINATE_1

NUMBER OF LAYERS = 3

DATA INPUT POINTS FOR CURVE FIT-

LAYER	THETA	T	E11	E22	V12	V21	G12	SQ1 Y	SQ1 Y	TAU Y
1	45.00	2.5000E+01	1.9R20E+05	1.9000E+04	2.5500E+01	2.4445E+02	5.7700E+03	2.1069E+00	2.1069E+00	6.5556E+01
2	0.00	5.0000E+01	1.9R20E+05	1.9000E+04	2.5500E+01	2.4445E+02	5.7700E+03	2.1069E+00	2.1069E+00	6.5556E+01
3	-45.00	2.5000E+01	1.9R20E+05	1.9000E+04	2.5500E+01	2.4445E+02	5.7700E+03	2.1069E+00	2.1069E+00	6.5556E+01

LAYER	THETA	T	E11	E22	V12	V21	G12	SQ1 Y	SQ1 Y	TAU Y
1	45.00	2.06700E+01	2.75600E+01	3.44500E+01	4.13400E+01	4.82300E+01	5.51200E+01			
2	15.000E-02	2.60000E-03	4.00000E-03	5.00000E-03	7.60000E-03	1.00000E-02	1.31000E-02	1.65000E-02	1.65000E-02	

LAYER	THETA	T	E11	E22	V12	V21	G12	SQ1 Y	SQ1 Y	TAU Y
1	45.00	1.37800E+01	2.06700E+01	2.75600E+01	3.44500E+01	4.13400E+01	4.82300E+01	5.51200E+01		
2	15.000E-02	2.60000E-03	4.00000E-03	5.00000E-03	7.60000E-03	1.00000E-02	1.31000E-02	1.65000E-02	1.65000E-02	

LAYER	THETA	T	E11	E22	V12	V21	G12	SQ1 Y	SQ1 Y	TAU Y
1	45.00	1.37800E+01	2.06700E+01	2.75600E+01	3.44500E+01	4.13400E+01	4.82300E+01	5.51200E+01		
2	15.000E-02	2.60000E-03	4.00000E-03	5.00000E-03	7.60000E-03	1.00000E-02	1.31000E-02	1.65000E-02	1.65000E-02	

LAYER	THETA	T	E11	E22	V12	V21	G12	SQ1 Y	SQ1 Y	TAU Y
1	45.00	1.37800E+01	2.06700E+01	2.75600E+01	3.44500E+01	4.13400E+01	4.82300E+01	5.51200E+01		
2	15.000E-02	2.60000E-03	4.00000E-03	5.00000E-03	7.60000E-03	1.00000E-02	1.31000E-02	1.65000E-02	1.65000E-02	

LAYER	THETA	T	E11	E22	V12	V21	G12	SQ1 Y	SQ1 Y	TAU Y
1	45.00	1.37800E+01	2.06700E+01	2.75600E+01	3.44500E+01	4.13400E+01	4.82300E+01	5.51200E+01		
2	15.000E-02	2.60000E-03	4.00000E-03	5.00000E-03	7.60000E-03	1.00000E-02	1.31000E-02	1.65000E-02	1.65000E-02	

LAYER	THETA	T	E11	E22	V12	V21	G12	SQ1 Y	SQ1 Y	TAU Y
1	45.00	1.37800E+01	2.06700E+01	2.75600E+01	3.44500E+01	4.13400E+01	4.82300E+01	5.51200E+01		
2	15.000E-02	2.60000E-03	4.00000E-03	5.00000E-03	7.60000E-03	1.00000E-02	1.31000E-02	1.65000E-02	1.65000E-02	

LAYER	THETA	T	E11	E22	V12	V21	G12	SQ1 Y	SQ1 Y	TAU Y
1	45.00	1.37800E+01	2.06700E+01	2.75600E+01	3.44500E+01	4.13400E+01	4.82300E+01	5.51200E+01		
2	15.000E-02	2.60000E-03	4.00000E-03	5.00000E-03	7.60000E-03	1.00000E-02	1.31000E-02	1.65000E-02	1.65000E-02	

EQUATION PARAMETERS

EXPONENT M = 2.74596E+00
EXPONENT N = 1.47384E+06

EXTERNALLY APPLIED STRESS

STRESS INCREMENT	INITIAL STRESS	NO. OF INCREMENTS
SG XX 5.00000E+00	SG YY -2.50000E+00	1.50000E+01
SG XY 0.		-7.50000E+00
		0.

LAMINA FAILURE CRITERIA

ALL FAILURE CRITERIA

LT

LL

ULT. STRESS
ULT. STRAIN

NOTE: ALL STRAINS ARE ENGINEERING COMPONENTS

1	TFNS. COMP.	1.32000E+03 2.43000E+03	7.16000E+01 2.75000E+02
1	TFNS. COMP.	6.68000E-03 1.22700E-02	3.77000E-03 1.45000E-02
2	TFNS. COMP.	1.32000E+03 2.43000F+03	7.16000E+01 2.75000E+02
2	TFNS. COMP.	6.68000E-03 1.22700E-02	3.77000E-03 1.45000E-02
3	TFNS. COMP.	1.32000E+03 2.43000E+03	7.16000E+01 2.75000E+02
3	TFNS. COMP.	6.68000E-03 1.22700E-02	3.77000E-03 1.45000E-02

LAYER

QUADRATIC INTERACTION TERM (A12)

1	*2.86230E-06
2	*2.86230E-06
3	*2.86230E-06

STIFFNESS = 1.00000E-01

CONTROL PARAMETERS

MAX. NO. OF ITERATIONS = 10
CONVERGENCE CRITERIA = 1.00000E-03
DIVERGENCE CRITERIA = ?.00000E+04

LAMINATE CONSTANTS (STRESS-STRAIN)

FXX	=	1.1189E+05
EYY	=	3.49464E+04
VYX	=	6.85449E-01
VXY	=	2.14203E-01
GXY	=	2.89885E+04

APPLIED STRESS ANALYSIS

EXTERNAL APPLIED STRESS

SG XX = 5.00000E+00
SG YY = -2.50000E+00
SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 2 ITERATIONS

STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			
LAYER	SG 11	SG 22	SG 12	EP XX	EP YY	
1	-5.44278E+00	-4.36113E-01	-9.62175E-01	6.18445E-05	-1.15643E-04	-7.23315E-13
2	1.9776E+01	-1.0907E+00	0.	6.18445E-05	*1.15643E-04	0.
3	-5.44278E+00	-4.36113E-01	9.62182E-01	6.18452E-05	*1.15644E-04	-7.41279E-13

EXTERNAL APPLIED STRESS

SG XX = 2.00000E+01
SG YY = -1.00000E+01
SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 3 ITERATIONS

STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			
LAYER	SG 11	SG 22	SG 12	EP XX	EP YY	
1	-2.54934E+01	-1.66973E+00	-2.74989E+00	2.61075E-04	-5.14162E-04	2.48289E-11
2	5.08018E+01	-3.69865E+00	0.	2.61075E-04	-5.14182E-04	0.
3	-2.54934E+01	-1.66973E+00	2.74964E+00	2.61039E-04	-5.14147E-04	2.45162E-11

EXTERNAL APPLIED STRESS

SG XX = 3.50000E+01
SG YY = -1.75000E+01
SG XY = 0.

SOLUTION FOR STRFSS CONVERGES WITHIN 4 ITERATIONS

STRFSS (LAYER AXES)			STRAIN (LAMINATE AXES)			
LAYER	SG 11	SG 22	SG 12	EP XX	EP YY	
1	-4.87608E+01	-2.72127E+00	-3.22333E+00	4.74559E-04	-9.59587E-04	-2.64055E-12
2	9.25187E+01	-6.03463E+00	0.	4.74559E-04	*9.59587E-04	0.
3	-4.87608E+01	-2.72227E+00	3.22336E+00	4.74565E-04	-9.59594E-04	-2.64345E-12

EXTERNAL APPLIED STRESS

SG XX = 5.00000E+01

SG YY = -2.50000E+01
SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 3 ITERATIONS

STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
LAYER	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22
1	-7.33712E+01	-3.76905E+00	-3.74695E+00	6.93289E-04	-1.42397E-03	-3.78710E-12	-3.65339E-04	-3.65339E-04
2	1.45323E+02	-8.18284E+00	0.	6.93289E-04	-1.42397E-03	0.	6.93289E-04	-1.42397E-03
3	-7.33712E+01	-3.76905E+00	3.24699E+00	6.93302E-04	-1.42398E-03	-3.79320E-12	-3.65339E-04	-3.65339E-04

EXTERNAL APPLIED STRESS

SG XX = 6.50000E+01
SG YY = -3.25000E+01
SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 2 ITERATIONS

STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
LAYER	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22
1	-9.05741E+01	-4.75320E+00	-3.15385E+00	9.13755E-04	-1.89622E-03	-2.15623E-12	-4.91231E-04	-4.91231E-04
2	1.78510E+02	-1.01825E+01	0.	9.3755E-04	-1.89622E-03	0.	9.13755E-04	-1.89622E-03
3	-8.05741E+01	-4.75320E+00	3.15387E+00	9.13765E-04	-1.89623E-03	-2.15636E-12	-4.91231E-04	-4.91231E-04

EXTERNAL APPLIED STRESS

SG XX = 8.00000E+01
SG YY = -4.00000E+01
SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 2 ITERATIONS

STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)			STRAIN (LAYER AXES)		
LAYER	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22
1	-1.24105E+02	-5.68706E+00	-3.03740E+00	1.13489E-03	-2.37258E-03	3.92971E-12	-6.18844E-04	-6.18844E-04
2	2.1859E+02	-1.0665E+01	0.	1.13489E-03	-2.37258E-03	0.	1.13489E-03	-2.37258E-03
3	-1.24105E+02	-5.68706E+00	3.03736E+00	1.13487E-03	-2.37256E-03	3.92220E-12	-6.18844E-04	-6.18844E-04

EXTERNAL APPLIED STRESS

SG XX = 9.50000E+01
SG YY = -4.75000E+01
SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 2 ITERATIONS
ETC.
:

STRESS (LAYER AXES)
 LAYER SG 11 SG 22
 1 -7.09459E+02 -2.12599E+01 -1.91901E+00
 2 1.1834E+03 -4.2721E+01 0.
 3 -7.09459E+02 -2.12599E+01 1.91901E+00

EXTERNAL APPLIED STRESS

SG XX = 4.25000E+02
 SG YY = -2.12500E+02
 SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 1 ITERATIONS

STRESS (LAYER AXES)
 LAYER SG 11 SG 22 SG 12
 1 -7.16579E+02 -2.148573E+01 -1.89844E+00
 2 1.22732E+03 -4.34H33E+01 0.
 3 -7.16579E+02 -2.148573E+01 1.89843E+00

EXTERNAL APPLIED STRESS

SG XX = 4.40000E+02
 SG YY = -2.20000E+02
 SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 1 ITERATIONS

STRESS (LAYER AXES)
 LAYER SG 11 SG 22 SG 12
 1 -7.43727E+02 -2.24492E+01 -1.87882E+00
 2 1.27121E+03 -4.50331E+01 0.
 3 -7.43727E+02 -2.24492E+01 1.87881E+00

LAMINATE HAS FAILED AT FIRST POST-FAILURE LOAD POINT
 EXTERNAL APPLIED STRESS
 SG XX = 4.55000E+02
 SG YY = -2.27500E+02
 SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 1 ITERATIONS

STRESS STRAIN (LAYER AXES)

STRAIN

STRESS (LAYER AXES)
 LAYER SG 11 SG 22
 1 6.02590E-03 -1.31302E-02 2.76845E-12
 2 6.02590E-03 -1.31302E-02 0.
 3 6.02590E-03 -1.31302E-02 2.75785E-12

EP XX EP YY EP XY
 6.02590E-03 -1.31302E-02 0.
 6.02590E-03 -1.31302E-02 0.
 6.02590E-03 -1.31302E-02 0.

EP 11 EP 22 EP 12
 -3.55216E-03 -3.55216E-03 -9.57806E-03
 6.02590E-03 -1.31302E-02 0.
 -3.55216E-03 -3.55216E-03 9.57801E-03

STRESS (LAYER AXES)
 LAYER SG 11 SG 22 SG 12
 1 6.24879E-03 -1.36252E-02 2.50081E-12
 2 6.24879E-03 -1.36252E-02 0.
 3 6.24874E-03 -1.36252E-02 2.49186E-12

EP XX EP YY EP XY
 6.24879E-03 -1.36252E-02 0.
 6.24879E-03 -1.36252E-02 0.
 6.24874E-03 -1.36252E-02 2.49186E-12

EP 11 EP 22 EP 12
 -3.6A822E-03 -3.6A822E-03 -9.93701E-03
 6.24879E-03 -1.36252E-02 0.
 -3.6A822E-03 -3.6A822E-03 9.91696E-03

STRESS (LAYER AXES)
 LAYER SG 11 SG 22 SG 12
 1 6.47171E-03 -1.41206E-02 2.26652E-12
 2 6.47171E-03 -1.41206E-02 0.
 3 6.47166E-03 -1.41205E-02 2.25905E-12

EP XX EP YY EP XY
 6.47171E-03 -1.41206E-02 0.
 6.47171E-03 -1.41205E-02 2.25905E-12

EP 11 EP 22 EP 12
 -3.87443E-03 -3.87443E-03 -1.02961E-02
 6.47171E-03 -1.41206E-02 0.
 -3.87443E-03 -3.87443E-03 1.02961E-02

STRESS STRAIN (LAYER AXES)

STRAIN

LAYER	SG 11	SG 22	SG 17	STRESS (LAYER AXES)			STRAIN (LAYER AXES)		
				EP XX	EP YY	EP XY	FP 11	EP 22	EP 12
1	-7.4090E+02	-2.3156E+01	-1.4600AE+00	6.69466E-03	-1.46162F-02	2.06077E-12	-3.9607AE-03	-3.9607AE-03	-1.06554E-02
2	1.31511E+03	-4.61719E+01	0.	6.69466E-03	-1.46162F-02	0.	6.69466E-03	-1.46162F-02	0.
3	-7.4090E+02	-2.3156E+01	1.46007F+00	6.69462E-03	-1.46162F-02	2.0543RE-12	-3.9607RF-03	-3.9607AE-03	1.06554E-02

++++ LAMINATE ANALYSIS INTERPOLATED 10 FAILURE POINT +++++

AT FAILURE
EXTERNAL APPLIED STRESS

SG XX = 4.54014E+02
SG YY = -2.27007F+02
SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 2 ITERATIONS

LAYER	SG 11	SG 22	SG 17	STRESS (LAYER AXES)			STRAIN (LAYER AXES)		
				EP XX	EP YY	EP XY	FP 11	EP 22	EP 12
1	-7.49113E+02	-2.29972E+01	-1.86128E+00	6.68000E-03	-1.45836F-02	1.07969E-13	-3.95181E-03	-3.95181E-03	-1.06318E-02
2	1.31222E+03	-4.61974E+01	0.	6.68000E-03	-1.45836F-02	0.	6.68000E-03	-1.45836E-02	0.
3	-7.49113E+02	-2.29972E+01	1.86128E+00	6.68000E-03	-1.45836F-02	1.07941E-13	-3.95181E-03	-3.95181E-03	1.06318E-02

LAMINATE HAS FAILED AT FIRST POST-FAILURE LOAD POINT
EXTERNAL APPLIED STRESS

SG XX = 4.70000F+02
SG YY = -2.35000F+02
SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 1 ITERATIONS

LAYER	SG 11	SG 22	SG 12	STRESS (LAYER AXES)			STRAIN (LAYER AXES)		
				EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	-8.18099E+02	-2.35116E+01	-1.44215E+00	6.91764E-03	-1.51122E-02	1.87914E-12	-4.09726E-03	-4.09726E-03	-1.10149E-02
2	1.35002E+03	-4.73000E+01	0.	6.91764E-03	-1.51122E-02	0.	6.91764E-03	-1.51122E-02	0.
3	-8.18099E+02	-2.35116E+01	1.44215E+00	3.1761E-03	-1.51121F-02	1.87378E-12	-4.09726E-03	-4.09726E-03	1.10149E-02

AT FAILURE
EXTERNAL APPLIED STRESS

SG XX = 4.56671E+02
SG YY = -2.28336E+02
SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 2 ITERATIONS

STRESS (LAYER AXES)						STRAIN (LAMINATE AXES)						
LAYER	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12	STRAIN (LAYER AXES)		
1	-7.93930E+02	-2.31006E+01	1.85804E+00	6.71450E-03	-1.46715E-02	1.96310E-12	-3.97598E-03	-3.97598E-03	-1.06955E+02			
2	1.32000E+03	-4.62811E+01	0.	6.71950E-03	-1.46715E-02	0.	6.71950E-03	-1.46715E-02	0.			
3	-7.03930E+02	-2.31006E+01	1.85803E+00	6.71947E-03	-1.46714E-02	1.95735E-12	-3.97598E-03	-3.97598E-03	-1.06954E+02			

EXTERNAL APPLIED STRESS

SG XX = 4.85000E+02
SG YY = -2.42500E+02
SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 1 ITERATIONS

STRESS (LAYER AXES)						STRAIN (LAMINATE AXES)						
LAYER	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12	STRAIN (LAYER AXES)		
1	-8.45322E+02	-2.41931E+01	-1.82498E+00	7.14066E-03	-1.56088E-02	1.71832E-12	-4.23386E-03	-4.23386E-03	-1.13745E+02			
2	1.40293E+03	-4.84179E+01	0.	7.14066E-03	-1.56084E-02	0.	7.14066E-03	-1.56084E-02	0.			
3	-8.45321E+02	-2.41931E+01	1.82498E+00	7.14062E-03	-1.56084E-02	1.71377E-12	-4.23386E-03	-4.23386E-03	-1.13745E+02			

EXTERNAL APPLIED STRESS

SG XX = 5.00000F+02
SG YY = -2.50000F+02
SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 1 ITERATIONS

STRESS (LAYER AXES)						STRAIN (LAMINATE AXES)						
LAYER	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12	STRAIN (LAYER AXES)		
1	-8.72567E+02	-2.47645E+01	-1.80852E+00	7.36370E-03	-1.61049E-02	1.57546E-12	-4.37059E-03	-4.37059E-03	-1.17343E+02			
2	1.44688E+03	-4.95298E+01	0.	7.36370E-03	-1.61049E-02	0.	7.36370E-03	-1.61049E-02	0.			
3	-8.72567E+02	-2.47645E+01	1.80851E+00	7.36365E-03	-1.61049E-02	1.57158E-12	-4.37059E-03	-4.37059E-03	-1.17343E+02			

LAMINATE HAS FAILED QUADRATIC INTERACTION FAILURE
 QUADRATIC = 1.0320 FOR LAYER 2
 QUADRATIC = .9714 FOR LAYER 2 OF PREVIOUS LOAD

AT FIRST POST-FAILURE LOAD POINT
 EXTERNAL APPLIED STRESS

SG XX = 5.1500E+02
 SG YY = -2.5750E+02
 SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 1 ITERATIONS

LAYER	SG 11	SG 22	SG 12	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)		
				EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	-8.99834E+02	-2.53313E+01	-1.79271E+00	7.58678E-03	-1.66017E-02	1.44798E-12	-4.50744E-03	-4.50744E-03	-1.20942E-02
2	1.49079E+03	-5.06245E+01	0.	7.58678E-03	-1.66017E-02	0.	7.58678E-03	-1.66017E-02	0.
3	-8.9834E+02	-2.53313E+01	1.79270E+00	7.58675E-03	-1.66016E-02	1.44462E-12	-4.50744E-03	-4.50744E-03	1.20942E-02

***** LAMINATE ANALYSIS INTERPOLATED TO FAILURE POINT *****

AT FAILURE
 EXTERNAL APPLIED STRESS

SG XX = 5.07082E+02
 SG YY = -2.53541E+02
 SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 2 ITERATIONS

LAYER	SG 11	SG 22	SG 12	STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)		
				EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	-8.45438E+02	-2.50327E+01	-1.40097E+00	7.46902E-03	-1.63339E-02	7.18620E-13	-4.43519E-03	-4.43519E-03	-1.19042E-02
2	1.46760E+03	-5.0457E+01	0.	7.46902E-03	-1.63339E-02	0.	7.46902E-03	-1.63339E-02	0.
3	-8.45438E+02	-2.50327E+01	1.40097E+00	7.46902E-03	-1.63339E-02	7.17842E-13	-4.43519E-03	-4.43519E-03	1.19042E-02

LAMINATE 2

5. NUMBER OF LAYERS = 2
LAYER THETA T
1 3n.00 5.0000E+01
2 -3n.00 5.0000E-01
EXONENT M = 3.0000E+00
EXONENT N = 3.0000E+00

EQUATION PARAMETERS

EXONFNT M = 3.0000E+00
EXONFNT N = 3.0000E+00

EXTERNALLY APPLIED STRESS

INITIAL STRESS
SG XX 5.00000E+01
SG YY 0.
SG XY 0.

NO. OF INCREMENTS

48

LAMINA FAILURE CRITERIA

ULTIMATE STRESS

LAYER LL TT
ULT. STRAIN

NOTE: ALL STRAINS ARE ENGINEERING COMPONENTS

1 TENS. COMP. 7.0000E-03 2.0000E-02
7.0000E-03 2.0000E-02
2 TENS. COMP. 7.0000E-03 2.0000E-02
7.0000E-03 2.0000E-02
STIFFNESS = 1.00000E-01

CONTROL PARAMETERS

MAX. NO. OF ITERATIONS = 10
CONVERGENCE CRITERIA = 1.00000E-03
DIVERGENCE CRITERIA = 2.00000E-04

LAMINATE CONSTANTS (STRESS-STRAIN)

EXX = 1.31210E+05
FYY = 8.96344E+04

VYX = 4.42435E-01
VXY = 3.02224E-01
GXY = 7.05386E+04

APPLIED STRESS ANALYSIS

EXTERNAL APPLIED STRESS

SG XX = 5.00000E+01
SG YY = 0.
SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 1 ITERATIONS

STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)		
LAYER	SG 11	SG 22	SG 12	EP XX	EP YY
1	5.17302E+01	-3.73016E+00	-1.22801E+01	3.83121E+04	-1.71772E+04
2	5.17302E+01	-3.73016E+00	1.22801E+01	3.83121E+04	-1.71772E+04

EXTERNAL APPLIED STRESS

SG XX = 2.50000E+02
SG YY = 0.
SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 2 ITERATIONS

STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)		
LAYER	SG 11	SG 22	SG 12	EP XX	EP YY
1	2.00731E+02	-3.07312E+01	-5.442261E+01	2.08896E+03	-1.15710E+03
2	2.00731E+02	-3.07313E+01	5.442261E+01	2.08896E+03	-1.15710E+03

EXTERNAL APPLIED STRESS

SG XX = 4.50000E+02
SG YY = 0.
SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 1 ITERATIONS

STRESS (LAYER AXES)			STRAIN (LAMINATE AXES)		
LAYER	SG 11	SG 22	SG 12	EP XX	EP YY
1	5.25892E+02	-7.58973E+01	-8.61013E+01	4.17109E+03	-7.93967E+03
2	5.25854E+02	-7.58900E+01	8.60956E+01	4.17132E+03	-7.93969E+03

EXTERNAL APPLIED STRESS

SG XX = 6.50000E+02
SG YY = 0.
SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 1 ITERATIONS

STRESS
(LAYER AXES)
LAYER SG 11 SG 22 SG 12 EP XX EP YY EP XY
1 7.0039E+02 -1.3051E+02 -1.12556E+02 6.64157E-03 -5.71879E-03 1.41357E-07
2 7.0052E+02 -1.3046E+02 1.12554E+02 6.64174E-03 -5.71877E-03 1.19534E-07

EXTERNAL APPLIED STRESS

SG XX = 8.50000F+02

SG YY = 0.

SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 1 ITERATIONS

STRESS
(LAYER AXES)
LAYER SG 11 SG 22 SG 12 EP XX EP YY EP XY
1 1.03875E+03 -1.8453E+02 -1.36434E+02 9.53059E-03 -9.66849E-03 1.48380E-06
2 1.03865E+03 -1.84747E+02 1.36422E+02 9.52839E-03 -9.66833E-03 1.31694E-06

EXTERNAL APPLIED STRESS

SG XX = 1.05000E+03

SG YY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 1 ITERATIONS

STRESS
(LAYER AXES)
LAYER SG 11 SG 22 SG 12 EP XX EP YY EP XY
1 1.29984E+03 -2.49716E+02 -1.58904E+02 1.28870E-02 -1.49782E-02 -2.27314E-06
2 1.29971E+03 -2.49933E+02 1.58895E+02 1.28838E-02 -1.49784E-02 -1.99637E-06

LAMINATE HAS FAILED AT FIRST POST-FAILURF EXCENS MAXIMUM

AT FIRST POST-FAILURF LOAN POINT

EXTERNAL APPLIED STRESS

SG XX = 1.25000F+03

SG YY = 0.

SG XY = 0.

SOLUTION FOR STRESS CONVERGES WITHIN 1 ITERATIONS

STRESS

STRAIN

STRAIN

(LAYER AXES)

(LAMINATE AXES)

(LAYER AXES)

LAYER	SG 11	SG 22	SG 12	EP XX	EP YY	EP XY	EP 11	EP 22	EP 12
1	$1.56228E+03$	$-3.12157E+02$	$-1.80593E+02$	$1.67730E-02$	$-2.18526E-02$	$-2.67009E-06$	$7.11545E-03$	$-1.21950E-02$	$-1.67260E-02$
2	$1.56215E+03$	$-3.12271E+02$	$1.80581E+02$	$1.67695E-02$	$-2.18529E-02$	$-2.32925E-06$	$7.11488E-03$	$-1.21983E-02$	$1.67234E-02$

***** PROGRAM TERMINATED *****

PROGRAM TERMINATED

5. Computer Program Listings

Source listings of both the UNI and NOLIN computer programs follow. The UNI program requires 20 K of computer core storage in a CDC 6600 machine, while the NOLIN program requires 60 K of core storage. No peripheral devices are required for either program for intermediate data storage.

5.1 UNI LISTING

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PROGRAM MAIN(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)

```

C
C UNI COMPUTES UNIDIRECTIONAL FIBER BUNDLE PROPERTIES, EXPANSION
C COEFFICIENTS AND RAMBERG-OSGOOD SHEAR STRESS PARAMETER FOR THE
C UNIDIRECTIONAL FIBER BUNDLE

C PRESENT VERSION INCLUDES:
C   1  TRANSVERSELY ISOTROPIC FIBER/ISOTROPIC MATRIX
C   2  AXIAL AND TRANSVERSE FIBER BUNDLE EXPANSION COEFFICIENTS
C   3  RAMBERG-OSGOOD SHEAR STRESS PARAMETER FOR THE UNIDIRECTIONAL
C      COMPOSITE AS DERIVED FROM THE RAMBERG-OSGOOD SHEAR STRESS PARAMETER
C      FOR THE MATRIX

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* INPUT PARAMETERS *

```

C   NF      I NO. OF FIBERS IN COMPOSITE
C   NM      I NO. OF MATRICES IN COMPOSITE
C   NVM     I NO. OF MATRIX VOL. FRACTIONS
C   EF(J)   I YOUNG'S MOD. FOR JTH FIBER
C   EM(J)   I YOUNG'S MOD. FOR JTH MATRIX
C   ANUF(J) I POISSON RATIO FOR JTH FIBER
C   ANUM(J) I POISSON RATIO FOR JTH MATRIX
C   RHOF(J) I DENSITY OF JTH FIBER
C   RHOM(J) I DENSITY OF JTH MATRIX
C   ALPM(J) I COEF. OF THERMAL EXPANSION FOR JTH MATRIX
C   VH(J)   I VOL. FRACTION FOR JTH MATRIX
C   ROMS(J) I SHEAR STRESS RAMBERG OSGOOD PARAMETER FOR JTH MATRIX
C   ALPF(J) I COEF. OF THERMAL EXPANSION FOR JTH FIBER
C   ALPFT(J) I TRANSVERSE THERMAL EXP. COEF. FOR JTH FIBER
C   EFA(J)  I AXIAL YOUNG'S MOD. FOR JTH FIBER
C   EFT(J)  I TRANSVERSE YOUNG'S MOD. FOR JTH FIBER
C   ANUFA(J) I AXIAL POISSON RATIO FOR JTH FIBER
C   GFA(J)  I AXIAL SHEAR MODULUS FOR JTH FIBER
C   ANUFT(J) I TRANSVERSE POISSON RATION FOR JTH FIBER

COMMON /AREAO1/EA(200),ETS(200),ANUAS(200),GAS(200),GTS(200),
      AKTS(200),ANUTS(200)
COMMON /AREAO2/L
COMMON /AREA03/RHO(200),ALPHA(3,200)
COMMON /AREAO4/EM(20),GM(20),VM(20),ANUM(20),ALPM(20),AKM(20)
COMMON /AREAO5/EM(20),GM(20),MV(20),ANUF(20),ALPF(20)
COMMON /AREAO7/AF(20),ALPF(20),ALPFT(20)
COMMON /AREAO8/RIGM(20),RIGKF(20)
COMMON /AREAO11/MF(20),MV(20),MM(200)
COMMON /AREAO10/ROCOMP(200),ROWS(20)
DIMENSION EF(20),ANUF(20),RHOF(20),RHOM(20),GF(20)
DIMENSION SM(3,3),SF(3,3)
DIMENSION EFA(20),EFT(20),ANUFA(20),ANUFT(20),GFA(20),GFT(20)
      (EF(1),EFA(1)),(GF(1)),GFA(1),(ANUF(1),ANUFA(1))

* VARIABLE DICTIONARY *

C
C CALCULATED THRMIC=ELASTIC CONSTITUENT PARAMETERS
C
C GFT(J)  I TRANSVERSE SHFAR MULUS FOR JTH FIBER

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C GF (J)   ! SHEAR MODULUS FOR JTH FIBER
C GM (J)   ! SHEAR MODULUS FOR JTH MATRIX
C AKF (J)  ! PLANE STRAIN BULK MODULUS FOR JTH FIBER
C AKM (J)  ! PLANE STRAIN BULK MODULUS FOR JTH MATRIX

C EFFECTIVE THERMOELASTIC PARAMETERS
C AKTS (J) ! EFFECTIVE AXIAL. BULK MOD. FOR JTH MATERIAL
C EAS (J)  ! EFFECTIVE AXIAL. YOUNG'S MOD. FOR JTH MATERIAL
C ETS (J)  ! EFFECTIVE TRANS. YOUNG'S MOD. FOR JTH MATERIAL
C ANUAS (J) ! EFF. POISSON RATIO (UNIDIRECTIONAL AX. STRESS) FOR JTH MATERIAL
C ANUTS (J) ! EFF. POISSON RATIO (IN TRANSVERSE PLANE) FOR JTH MATERIAL
C GAS (J)   ! EFF. SHEAR MOD. (IN FIBER PLANES) FOR JTH MATERIAL
C GTS (J)   ! EFF. SHEAR MOD. (IN TRANS. PLANES) FOR JTH MATERIAL
C ALPAS (J) ! EFF. (FIBER DIRECTION) THERMAL EXP. COEF. FOR JTH MATERIAL
C ALPTS (J) ! EFF. (TRANS. DIRECTION) THERMAL EXP. COEF. FOR JTH MATERIAL
C RHOS (J)  ! BULK DENSITY FOR JTH MATERIAL
C ROCOMP(J): RAMMER-GOGG SHEAR STRESS PARAMETER FOR JTH MATERIAL

C UNI MAY BE USED AS A SUBROUTINE
C SUBROUTINES REQUIRED : MSUB01,MSUB02
C ****
C INITIALIZE VARIABLES TO ZERO.
C NAMELIST/DATAONE/NF,NM,NVM,EF,ANUF,RHOF,EFA,ANUFA,GFA,EFT,ANUFT,
C IEM,ANUM,RHOM,VM,ROMS,ALPF,ALPM,ALPM
C DATA EFT/20*0.0/
C DATA ROMS/20*0.0/
C DATA ALPM/20*0.0/
C 171 CONTINUE
C READ(5,DATAONE)
C IF (EFT<5) 172,173
C 000003 173 CONTINUE
C 000011 1012,1012,1014
C 000013 1012 CONTINUE
C 000013 DO 3 J=1,NF
C 000015 IF (J.NE.1) GO TO 4
C 000017 WRITE(6,202)
C 000022 IF (ALPM(1))5,5,6
C 000024 5 WRITE(6,203)
C 000030 6 GO TO 4
C 000031 6 WRITE(6,204)
C 000035 4 GF (J) = EF (J) / ((1.0+ANUF (J))*2.0)
C 000042 AKF (J) = GF (J)/(1.0-2.0*ANUF (J))
C 000046 IF (ALPM(1))8,B,Q
C 000050 8 WRITE(6,205) (J,EF (J),ANUF (J),GF (J),AKF (J),RHOF (J))
C 000070 9 GO TO 3
C 000071 9 WRITE(6,206) (J,EF (J),ANUF (J),GF (J),AKF (J),RHOF (J),ALPF (J))
C 000113 3 CONTINUE
C 000116 6 GO TO 1018
C 000116 1014 CONTINUE
C 000116 DO 503 J=1,NF
C 000116 IF (J.NE.1) GO TO 504

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MAIN

```
000122      TF(ALPM(1))505,505,506
000123      505 WRITE(6,203)
000124      GO TO 504
000127      506 WRITE(6,204)
000130      504 CONTINUE
000134      GFT(J) = EFT(J) / ((1.0+ANUFT(J))*2.0)
000141      AKF(J)=EFA(J)*EFT(J)/(2.*EFA(J)*(1.-ANUFT(J))-4.*EFT(J)*
1. ANUFA(J)*#*2)
000154      IF(ALPM(1))508,508,509
000155      WRITE(6,205)(J,EFA(J)*GFA(J),AKF(J),RHOF(J))
000175      WRITE(6,205)(J,EFT(J)*ANUFT(J),AKF(J),RHOF(J))
000215      GO TO 503
000216      509 WRITE(6,206)(J,EFA(J)*ANUFA(J),GFA(J),AKF(J),RHOF(J)*ALPF(J))
000240      WRITE(6,206)(J,EFT(J)*ANUFT(J),GFT(J),AKF(J),RHOF(J)*ALPFT(J))
000262      503 CONTINUE
000265      1018 CONTINUE
000265      DO 10 J = 1,NM
000267      IF (J.NF.1) GO TO 11
000271      IF(ALPM(1))12,12,13
000272      12 WRITE(6,207)
000276      13 GO TO 11
000277      13 WRITE(6,208)
000303      11 GM(J) = EM(J)/((1.0+ANUM(J))*2.0)
000310      AKM(J) = GM(J)/(1.0-2.0*ANUM(J))
000314      IF(ALPM(1))14,14,15
000315      14 WRITE(6,205)(J,EM(J)*ANUM(J),GM(J)*AKM(J),RHOM(J))
000335      15 GO TO 10
000336      15 WRITE(6,206)(J,EM(J)*ANUM(J),GM(J)*AKM(J),RHOM(J))
000360      10 CONTINUE
C      IF(ROMS(1).EQ.0)GO TO 777
000364      WRITE(6,217)
000367      777 NM=NM
C      CALCULATE THE EFFECTIVE THERMO-ELASTIC PARAMETERS
000367      00021300
000403      C      FORM FIBER COMPLIANCE MATRIX
000404      00021400
000405      00021600
000405      00021700
000405      DO 100 I=1,NF
C      FORM FIBER COMPLIANCE MATRIX
000407      911 IF(ALPM(1))910,910,911
000410      911 IF(EFT(1).EQ.0)CALL MSUB01(T,EF,EF,ANUF,ANUF,SF)
000415      912 IF(EFT(1).NE.0)CALL MSUB01(T,EFA,EFT,ANUF,ANUF,T,SF)
000422      910 CONTINUE
000422      DO 100 J=1,NM
C      FORM MATRIX COMPLIANCE MATRIX
000424      913 IF(ALPM(1))912,912,913
000425      913 CALL MSUB01(J,EM,EM,ANUM,ANUM,SM)
000431      912 CONTINUE
000431      00021900
000433      00022000
000435      L=L+1
000437      MM(L)=J
000437      MF(L)=1
000440      MV(L)=K
000441      VF=1.0-VM(K)
```

```

ROCOMP(L)=ROMS(J)*SQRT((3.*((1.+VF)**3/(3.+13.*VF**2*VF**3)))
P1 = VM(K)*AKM(J)*(AKF(I)+GM(J)+VF*AKF(I)*(AKM(J)+GM(J))
Q1 = VM(K)*(AKF(I)+GM(J))+VF*(AKM(J)+GM(J))
AKTS(L) = P1/Q1
IF (EFT(I)) 1022,1022,1026
 1022 CONTINUE
    P2 = 4.0*(ANUF(I)-ANUM(J))*(ANUF(I)-ANUM(J))*VF*VM(K)
    Q2 = VM(K)/AKF(I)+VF/AKM(J)+1.0/GM(J)
    EAS(L) = VF*EM(I)+EM(J)*P2/Q2
    P3 = VF*VM(K)*(ANUF(I)-ANUM(J))*1.0/AKM(J)-1.0/AKF(I)
    Q3 = Q2
    ANUAS(L) = VF*ANUF(I)+VM(K)*ANUM(J)+P3/Q3
    P4 = VM(K)*GM(J)+(1.0+VF)*GF(I)
    Q4 = (1.0+VF)*GM(J)+VM(K)*GF(I)
    GAS(L) = GM(J)*P4/Q4
    GAMMA = GF(I)/GM(J)
    RETAM = 1.0/(3.0-4.0*ANUM(J))
    RETAF = 1.0/(3.0-4.0*ANUF(I))
    GO TO 1028
 1026 CONTINUE
    P2 = 4.0*(ANUF(I)-ANUM(J))*(ANUF(I)-ANUM(J))*VF*VM(K)
    Q2 = VM(K)/AKF(I)+VF/AKM(J)+1.0/GM(J)
    EAS(L) = VF*EM(I)+VM(K)*EM(J)*P2/Q2
    P3 = VF*VM(K)*(ANUF(I)-ANUM(J))-1.0/AKF(I)
    Q3 = Q2
    ANUAS(L) = VF*ANUF(I)+VM(K)*ANUM(J)+P3/Q3
    P4 = VM(K)*GM(J)+(1.0+VF)*GFA(I)
    Q4 = (1.0+VF)*GM(J)+VM(K)*GFA(I)
    GAS(L) = GM(J)*P4/Q4
    GAMMA = GFT(I)/GM(J)
    RETAM = 1.0/(3.0-4.0*ANUM(J))
    RETAF = 1.0/(1.0+(2.0*GFT(I))/AKF(I))
    GO TO 1028
 1028 CONTINUE
    ALEF = 1.E50
    IF (GAMMA<=1.0) ALEF = (GAMMA*RETAM)/(GAMMA-1.0)
    RP = GAMMA*BEТАF
    R = (BEТАM-RP)/(1.0+RP)
    VF3 = VF*VF*VF
    VM2 = VM(K)*VM(K)
    RETAM2 = RETAM*RETAM
    X1 = 1.0*R*VF3
    X2 = 3.0*VF*VM2*RETAM2
    P5 = (ALEF+BEТАM*VF)*X1-X2
    Q5 = (ALEF-VF)*X1-X2
    IF (GAMMA>=1.0) GTS(L)=GM(J)
    IF (GAMMA<=1.0) GTS(L)=GM(J)*P5/Q5
    P6 = 4.0*AKTS(L)*GTS(L)
    Q6 = AKTS(L)*(1.0+4.0*AKTS(L)*ANUAS(L)/EAS(L))*GTS(L)
    ETS(L) = P6/Q6
    ANUTS(L) = 0.5*(ETS(L)/GTS(L))-1.0
    IF (ALPM(I)>2.0) 920
    IF (EFT(I)<0) GO TO 921
    BIGKM(J) = EM(J)/(3.0*1.0-2.0*ANUM(J))
    RIGKF(I) = EF(I)/(3.0*(1.0-2.0*ANUF(I)))
    PARRK = VM(K)/IGKM(J)+VF*BTGKF(I)
 920
 000443
 000463
 000474
 000505
 000510
 000511
 000512
 000527
 000537
 000553
 000562
 000571
 000577
 000603
 000605
 000611
 000616
 000616
 000625
 000634
 000644
 000656
 000660
 000667
 000676
 000704
 000710
 000712
 000716
 000723
 000725
 000733
 000735
 000741
 000742
 000744
 000746
 000751
 000754
 000761
 000763
 000770
 000776
 001001
 001012
 001014
 001020
 001021
 001022
 001030
 001035
 00022200
 00022300
 00022400
 00022500
 00022600
 00022700
 00022800
 00022900
 00023000
 00023100
 00023200
 00023300
 00023400
 00023500
 00023600
 00023800
 00023900
 00024000
 00024100
 00024200
 00024300
 00024400
 00024500
 00024600
 00024800
 00024900
 00025000
 00025100
 00025400
 00025500

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001042      ALBAR = VF*ALPF(I)*VM(K)*ALPM(J)          00025600
001046      F1 = 0.*0.                                     00025600
001047      IF(BIGKM(J).NE.BIGKF(I)) F1 = (ALPM(J)*ALPF(I))/1
1 (1.0/BIGKM(J)-1.0/BIGKF(I))
001061      F2 = (3.0*(1.0 - 2.0*ANUAS(L))/EAS(L)          00025800
001067      ALPHA(1,L) = ALBAR + F1*(F2 - BARRK)          00025900
001074      ALPHA(2,L) = ALBAR + F1*(3.0/(2.*AKTS(L)) - ANUAS(L)*F2 - BARRK)
001106      GO TO 20
001106      921 CONTINUE

C   FORM COMPOSITE COMPLIANCE MATRIX AND CALCULATE MATERIAL THERMAL
C   EXPANSION COEFFICIENTS
CALL MSUB02(I,J,KVF,SM)          00026100
001106      20 RHOS(LL) = VM(K)*RHOM(J)*VF*RHOF(I)
KLINE = KLINE+3                  00026200
001120      IF (KLINE.LE.48) GO TO 22
KLINE = 0                         00026300
001124      WRITE(6,215)               00026400
001125      22 IF(ALPM(I))23,23,24               00026500
001130      23 WRITE(6,209)               00026700
001132      24 WRITE(6,210)               00026800
001136      25 WRITE(6,211) I,J,L,VM(K)*EAS(L),ANUAS(L),GAS(L),AKTS(L) 00027100
001137      26 WRITE(6,213) I,J,L,VM(K)*EAS(L),ANUAS(L),GAS(L),AKTS(L)*ALPHA(1,L) 00027400
001143      27 WRITE(6,214) I,J,L,VM(K)*EAS(L),ANUAS(L),GAS(L),RHOS(L),ALPHA(2,L) 00027500
001145      28 WRITE(6,212) ETS(L),ANUTS(L),GTS(L),RHUS(L)          00027200
001171      29 WRITE(6,218) RCOMP(L)               00027600
001205      30 WRITE(6,219) RCOMP(L)               00015000
001206      31 WRITE(6,220) RCOMP(L)               00015500
001235      32 WRITE(6,221) RCOMP(L)               00015800
001254      33 WRITE(6,222) RCOMP(L)               00015900
001263      34 WRITE(6,223) RCOMP(L)               00016000
001273      35 WRITE(6,224) RCOMP(L)               00016100
001273      36 WRITE(6,225) RCOMP(L)               00016200
001277      STOP
001277      37 FORMAT(1IRI4)          00015100
001301      38 FORMAT(1P6E12.5)          00015200
001301      39 FORMAT(1H1)//42X37HCONSTITUENT THERMO-ELASTIC PARAMETERS) 00015300
001301      40 FORMAT(1//1JH FIBER NO.,11X4HE(F),12X5HNU(F),11X4HK(F)+12X4HK(F)+00015400
111X6HRHO(F),//)
001301      41 FORMAT(1//1JH FIBER NO.,11X4HE(F),12X5HNU(F),11X4HK(F),00015500
111X6HRHO(F),9XHALPHAF(F),//)
001301      42 FORMAT(1//12H MATRIX NO.,11X4HE(M),12X5HNU(M),11X4HG(M), 00015600
112X4HK(M),11X6HRHO(M),9XHALPHAM(F),//)
001301      43 FORMAT(1//12H MATRIX NO.,10X4HE(M),12X5HNU(M),11X4HG(M), 00015700
112X4HK(M),11X6HRHO(M),9XHALPHAM(M),//)
001301      44 FORMAT(1//3X1HF,3X1HM,3X8HMATERIAL,6X4HV(M),13X5HE(A)*10X6HNU(A),*11X5HG(T)*, 00015800
1*11X5HG(A)*,11X5HK(T)*,42X5HE(T)*,10X6HNU(T)*,11X5HG(T)*, 00015900
211X4HRHO*)          00016000
001301      45 FORMAT(1//3X1HF,3X1HM,3X8HMATERIAL,6X4HV(M),13X5HE(A)*, 00016100
110X6HNU(A)*,11X5HG(A)*,11X5HK(T)*,9X9HALPHA(A)*, 00016200
242X5HE(T)*,10X6HNU(T)*,11X5HG(T)*,11X4HRHO*,10X9HALPHA(T)*, 00016300
001301      46 FORMAT(1/214*17*615*5.4*X4G16.5), 00016400
001301      47 FORMAT(14X4G16.5), 00016500
001301      48 FORMAT(14X4G16.5), 00016600
001301      49 FORMAT(110X6HNU(A)*,11X5HG(A)*,11X5HK(T)*,9X9HALPHA(A)*, 00016700
242X5HE(T)*,10X6HNU(T)*,11X5HG(T)*,11X4HRHO*,10X9HALPHA(T)*, 00016800
001301      50 FORMAT(14X4G16.5), 00016900
001301      51 FORMAT(14X4G16.5), 00017000
001301      52 FORMAT(14X4G16.5), 00017100

```



```

C   SUBROUTINE MSUB01(I,A,B,C,D,VAR)
C   ROUTINE MSUB01 FORMS COMPLIANCE MATRIX FOR CONSTITUENTS
C   * VARIABLE DICTIONARY *
C
C     A(I)      : LONGITUDINAL MODULUS FOR ITH FIBER/MATRIX
C     B(I)      : TRANSVERSE MODULUS FOR ITH FIBER/MATRIX
C     C(I)      : LONGITUDINAL POISSON RATIO FOR ITH FIBER/MATRIX
C     D(I)      : TRANSVERSE POISSON RATION FOR ITH FIBER/MATRIX
C     VAR(J,K)  : COMPLIANCE MATRIX
C
C   * PROGRAMMING INFORMATION *
C
C   MSUB01 IS CALLED FROM : UNI
C *****
C
C
C000011 DIMENSION A(20),B(20),C(20),D(20),VAR(3,3)
C000012 VAR(1,1) = 1./A(1)
C000013 VAR(2,2) = 1./B(1)
C000015 VAR(3,3) = VAR(2,2)
C000017 VAR(1,2) = -C(1)/A(1)
C000022 VAR(1,3) = VAR(1,2)
C000023 VAR(2,3) = -D(1)/B(1)
C
C000026 RETURN
C000027 END

```

RUN VERSION 2.3 --PSR LEVEL 363--

07/09/74

```
C SUBROUTINE MSUB02(I,J,K,VF,SF,SM)
C ROUTINE MSUB02 FORMS COMPOSITE COMPLIANCE MATRIX FOR FIBER BUNDLES
C DEFINED IN ROUTINE UNI AND CALCULATES MATERIAL THERMAL
C EXPANSION COEFFICIENTS FOR TRANSVERSELY ISOTROPIC FIBER
C
C * VARIABLE DICTIONARY *
C
C MSUB02 IS CALLED FROM 1 UNI
C COMMON /AREA01/EAS(200),ETS(200),ANUAS(200),GAS(200),GTS(200),
C 1 COMMON /AREA02/L,
C COMMON /AREA03/RHO(200),ALPHA(3,200)
C COMMON /AREA04/EM(20),GM(20),VM(20),ANUM(20),ALPM(20),AKM(20)
C COMMON /AREA07/AKF(20),ALPF(20),ALPFT(20)
C COMMON /AREA10/BIGKM(20),RIGKF(20)
C COMMON /AREA11/MF(200),MV(200),MM(200)
C DIMENSION SF(3,3),SM(3,3),SC(3,3),SD(3,3),ABAR(12)
C DIMENSION SV(3,3),S(3,3),SD(3,3),ABAR(12)
C *****
C
C CALCULATE ALPHA FOR ANISOTROPIC FIBER CASE
C SC(1,1,L) = 1*EAS(L)
C SC(2,2,L) = 1*ETS(L)
C SC(3,3,L) = SC(2,2,L)
C SC(1,2,L) = -ANUAS(L)/EAS(L)
C SC(1,3,L) = SC(1,2,L)
C SC(2,3,L) = -ANUTS(L)/ETS(L)
C
C EXP1 = SC(1,1,L) = SM(1,1)
C EXP2 = SF(2,2) + SF(2,3) - SM(2,2) - SM(2,3)
C EXP3 = SM(1,2) - SC(1,2,L)
C EXP4 = SF(1,2) - SM(1,2)
C EXP5 = SF(1,1) - SM(1,1)
C EXP6 = SC(2,2,L) + SC(2,3,L) - SM(2,2) - SM(2,3)
C DAA = ALPF(I) - ALPM(J)
C DAT = ALPFT(I) - ALPM(J)
C
C EXP1 = (DAA * (EXP1*EXP2 + 2.*EXP3*EXP4)
C * +2.*DAT * (-EXP1*EXP4 - EXP3*EXP5)) /
C * ALPHA(1,L) = (EXP5*EXP2 - 2.*EXP4*EXP4)
C * ALPHA(1,L) = ALPHA(1,L) ALPM(J)
C * ALPHA(2,L) = (DAA * (-EXP3*EXP2 - EXP4*EXP6) +
C * DAT * (EXP5*EXP6 + 2.*EXP4*EXP3)) /
C * ALPHA(2,L) = (EXP5*EXP2 - 2.*EXP4*EXP4)
C * ALPHA(2,L) = ALPHA(2,L) ALPM(J)
C
C RETURN
C
C 000135
C 000135 FNIN
```

```

PROGRAM MAIN(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
REAL IAMG
DIMENSION
1 F11(20),E22(20),V12(20),V21(20),G12(20),
SCY(20),STY(20),TY(20),
T(20),IANG(20),
S11(20),S12(20),S21(20),S22(20),S44(20),
SINS(20),COS(20),SIN2(20),COS2(20),
P11(20),P22(20),P12(20),
FP11(20),EP22(20),EP12(20),
FPS11(20),FPS22(20),EPS12(20),
AT(60),DC(60),
F(3,20),G(3,20),H(3,20),
A(60,60),DR(60,60),SG(60,1),SF(60),
ULT(6,2,20),
SGS(60),S61(60,1),
STRN(50)*STRN(50),AO(100)*POINTS(50,6,20),
STX(20,50),STY(20,50),STXY(20,50),
EXX(50),EYY(50),VXY(50),VYX(50),GX(5n),
A11(20),A22(20),A44(20),A12(20),B1(20),B2(20),
EPN(60,1),PS(60),
DIMENSION MATYPE(20),S11T(20),S22T(20),
1 S11C(20),S22C(20),EP11C(20),EP22C(20),GAMA(20),EP11T(20),
2 EP22T(20),SIG11(50,20),SIG22(50,20),SIG12(50,20),
C COMMON /SET01/ E11,E22,V12,V21,G12
COMMON /SET02/ TT,IANG
COMMON /SET03/EP11,EP22,EP12
COMMON /SET04/ S01,S022,S012,S011,SM22,SM12
COMMON /SET05/ ULT,STIFF
COMMON /SET06/ SIN2,COS2,SINS,COS
COMMON /SET07/EP511,EP522,EP512
COMMON /SET08/ S11,S22,S12,S21
COMMON /SET09/LA,EUPT,COPT,IFCN,KSGM,INMT,RATIO,SENS
COMMON /SET10/ STY,SCY,XM,XN
COMMON /SET11/ EPS,UPRD,NIT,IT,SMLT
COMMON /SET12/ F,G,H
COMMON /SET13/ EXX,EYY,VXY,SSTXX,SSTYY,SSTXY
COMMON /SET14/ A11,A22,A44,A12,B1,B2
COMMON /SET15/ POINTS,IPRINT,ITOP,IPIS,LUP
COMMON /SET16/ MATYPE,S11T,S11C,S221,S22C,EP11T,EP11C,
1 EP22T,EP22C,GAMA,S1611,SIG22,SIG12
C LOGICAL
INTGER
INTGER
C FOUTVALENCE
C
C ARITHMETIC STATEMENT FUNCTIONS
C PBO(X,Y,W) = 1.0/(X*Y)**(1.0/(W-1.0))
C
C PROGRAM REQUIREMENTS *

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07/23/94

MAIN
RUN VERTON 2.3 --PSR LEVEL 363--  

C SUBROUTINES : LAMTSI•OUTPT1•PROP•REGAI•QUADCF•INVRD•CMATX•  

C : CONVR•HEADER ANGLE•MXMULD•TRANS•RESET•NRIRM•  

C : MATCH•LAYSUH  

C FUNCTION SUBPROGRAM : SINT  

C BLOCK DATA SUBPROGRAM : INITIALIZE VARIABLES IN COMMON SETS  

C : 01•05•10•11, AND 14  

C  

C LAYFRS : LIMITATIONS *  

C CURVE-FIT DATA POINTS : 20  

C INCREMENTS : 50  

C  

C EPS = 1.00E-03  

C UPBD = 2.00E+04  

C IT = 100  

C A12(I) = 0.00 (FOR ALL LAYERS)  

C XM = 3.00E 0 0  

C XN = 3.00E 0 0  

C INMT = 2  

C  

C * LIMITATIONS *  

C * DEFAULT VALUES *  

C  

C NST : NO. OF SEPARATE LAMINATES  

C IOPT : INPUT OPTION  

C : #1: INPUT RAMBERG-OZGOOD PARAMETERS TY•STY•SCY•XM•XN  

C : #2: DETERMINE RAMBERG-OZGOOD PARAMETERS FROM CURVE-FIT  

C EOPT : EXPONENT OPTION FOR CURVE-FIT ROUTINE  

C : #1: CURVE-FIT FOR ALL RAMBERG-OZGOOD PARAMETERS  

C : #3: INPUT EXPONENTS, XM + XN, CURVE-FIT TY•STY•SLY  

C COPT : LAYER OPTION FOR CURVE-FIT ROUTINE  

C : #1: USE SAME STRESS-STRAIN DATA FOR ALL LAYERS  

C : #2: STRESS-STRAIN DATA INPUT FOR EACH LAYER  

C  

C LAMINATE PROPERTIES  

C LAY : NO. OF LAYERS IN LAMINATE  

C E11(I) : AXIAL YOUNG'S MODULUS (LAYER I)  

C F22(I) : TRANSVERSE YOUNG'S MODULUS (LAYER I)  

C V12(I) : AXIAL-TRANSVERSE POISSON RATIO (LAYER I)  

C G12(I) : IN-PLANE SHEAR MODULUS (LAYER I)  

C IANG(I) : ANGULAR ORIENTATION (DEGREES) OF ITH LAYER  

C T(I) : THICKNESS OF ITH LAYER  

C  

C CURVE-FIT PARAMETERS  

C IPTS : NO. OF DATA POINTS  

C STRS(I) : ITH STRESS DATA POINT  

C STRN(I) : ITH STRAIN DATA POINT  

C POINTS --- COMPONENT  

C 1 = SIGMA 11  

C 2 = EPSILON 11  

C 3 = SIGMA 22  

C 4 = EPSILON 22  

C 5 = SIGMA 12  

C 6 = EPSILON 12

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C LOADING PARAMETERS
C S011 : AXIAL APPLIED LOAD
C S022 : TRANSVERSE APPLIED LOAD
C S012 : APPLIED SHEAR
C IFCN : FAILURE OPTION
C      : =1! ULTIMATE STRESS
C      : =2! QUADRATIC INTERACTION
C      : =3! ULTIMATE STRAIN
C      : =4! ALL FAILURE OPTIONS
C ULT(I,J,K) : LIMIT VALUE FOR LAYER K IN DIRECTION I (AXIAL,TRANSVERSE,
C               OR SHEAR) UNDER J (TENSION OR COMPRESSION)
C STIFF : RATIO (TANGENT MODULUS TO INITIAL MODULUS) AT
C         WHICH COMPUTATIONS TERMINATE
C A12(I) : QUADRATIC INTERACTION TERM (LAYER I)
C CONTROL SENTINELS
C KSGM : INCREMENTATION LIMIT
C SMLT : MULTIPLICATIVE FACTOR FOR LOAD INCREMENTS
C IT : ITERATION LIMIT PER NEWTON-RAPHSON ANALYSIS
C FPS : CONVERGENCE CRITERIA
C UPBN : CONVERGENCE CRITERIA
C TNMT : INCREMENTATION ESTIMATE METHOD

* VARIABLE DICTIONARY *

A0(I) : CURVE-FIT PARAMETER
RBO(X,Y,W) : CONVERSION FUNCTION FROM CURVE-FIT PARAMETERS
TT : TO RAMRERG-OSGOOD PARAMETERS
TT : TOTAL THICKNESS
TG(I+1) : RESULTANT AXIAL STRESS FOR ITH LAYER
SG(I+LAY+1) : RESULTANT TRANSVERSE STRESS FOR ITH LAYER
SG(I+2*LAY+1) : RESULTANT SHEAR ITH LAYER
SGS(I) : AXIAL STRESS (ITH LAYER) FROM PREVIOUS INCREMENT
SGS(I+LAY) : TRANSVERSE STRESS (ITH LAYER) FROM PREVIOUS LOAD
SGS(I+2*LAY) : SHEAR (ITH LAYER) FROM PREVIOUS LOAD
SG0(I+1) : INITIAL LOAD
S1(I) : COMPLIANCE TERM
S12(I) : COMPLIANCE TERM
S21(I) : COMPLIANCE TERM
S22(I) : COMPLIANCE TERM
S44(I) : COMPLIANCE TERM
SINS(I) : SQUARE OF SIN OF ITH LAYER
COS2(I) : SQUARE OF COS OF ITH LAYER
SIN2(I) : TWICE SIN OF ITH LAYER
COS2(I) : TWICE COS OF ITH LAYER
A (I,J) : INITIAL TRANSFORMATION MATRIX
DB(I,J) : MATRIX OF DERIVATIVE TERMS FOR N.-R. APPROX.
DC(I) : MULTIPLIER OF DERIVATIVE MATRIX (DB)
RT(I) : INCREMENTAL CHANGE IN STRESS SOLUTION BETWEEN
N.-R. ITERATES
SG1(I,1) : STRESS SOLUTION FROM PREVIOUS NEWTON-RAPHSON
ITERATION FOR A GIVEN LOAD
P11(I) : AXIAL STRAIN LAYER AXES (ITH LAYER)
P22(I) : TRANSVERSE STRAIN LAYER AXES (ITH LAYER)

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P12(I)
C   : SHEAR STRAIN LAYER AXES (ITH LAYER)
C   : AXIAL STRAIN LAMINATE AXES (ITH LAYER)
C   : TRANSVERSE SIRKAN LAMINATE AXES (ITH LAYER)
C   : SHFAR STRAIN LAMINATE AXES (ITH LAYER)
C   : MULTIPLICATION FACTOR USED TO ESTIMATE INITIAL.
C
C   PS(I,      )          : STRESS IN SUCCESSIVE LOADS
C   PS(I+, LAY)          : AXIAL STRAIN LAYER AXES (ITH LAYER) PREVIOUS LOAD
C   PS(I+2*,LAY)         : TRAN. STRAIN LAYER AXES (ITH LAYER) PREVIOUS LOAD
C   PS(I+3*,LAY)         : SHFAR STRAIN LAYER AXES (ITH LAYER) PREVIOUS LOAD
C   FPS1(I)              : AXIAL STRAIN LAMINATE AXES (ITH LAYER) PREVIOUS LOAD
C   FPS2(I)              : TRAN. STRAIN LAMINATE AXES (ITH LAYER) PREVIOUS LOAD
C   EPS12(I)             : SHFAR STRAIN LAMINATE AXES (ITH LAYER) PREVIOUS LOAD
C
C   SWITCH               : FAILURE SENTINEL
C   : =01 NO FAILURE
C   : =21 FAILURE. INTERPOLATE LOAD TO FAILURE POINT
C   NIT      NSR           : ! NEWTON-RAPHSON ITERATION COUNTER
C   : NON-STANDARD RETURN. NSR=1 IF AN END-OF-FILE IS TRUE
C
C   *****INITIALIZE VARIABLES*****
C
C   EX#3.
C   TNMT=2
C   RATIO=1.E-06
C   SENS=1.E-15
C
C   PRINT PROGRAM HEADER
C   CALL HEADER
C   NST=1
C   423 CONTINUE
C   NSR=0
C   TPRINT=0
C   CALL MATCRL (NSR)
C   TF (NSR,FQ=1) GO TO 424
C   CHANGE ENGINEERING STRAIN TO TENSORIAL STRAIN.
C
C   425 DO 63 ILKA=1,50
C   63 DO 43 ILKB=1,20
C   63 POINTS(ILKA,6,ILKA) = POINTS(ILKA,6,ILKB)/2.
C
C   *****INPUT*****
C   INPUT 1,
C   INPUT PER. SET
C   *
C
C   GO TO (20+30),IOPT
C   20 CONTINUE
C   GO TO 50
C   INPUT 2:
C
C   30 CONTINUE
C   IF (COPT.FQ=1) LUP=1
C   IF (COPT.FQ=2) LUP=LAY
C   40 IL=1,LU
C   INPUT STRESS-STRAIN DATA AND FIT CURVE OF FORM!

```

```

C      STRN = A0 + A1*STRS**EX
C      WHERE A0 = A*STRS
C      NO 40 IC=1•3
C      NO 45 INT=1•IPTS
C      STRN(IDT)=POINTS(IDT,2*IC•LUP)
C      STRS(IDT)=POINTS(IDT,2*IC-1•LUP)
C      IF(IC•EQ.1) A0(IDT) = STRS(IDT)/E12(IL)
C      IF(IC•EQ.2) A0(IDT) = STRS(IDT)/E22(IL)
C      IF(IC•EQ.3) A0(IDT) = STRS(IDT)/E22(IL)
C      STRN(IDT) = STRN(IDT) - A0(IDT)
C      IF(STRN(IDT).LE.1.0E-20) STRN(IDT) = 0.00
C      35 CONTINUE
C      LEAST-SQUARES CURVE-FIT FOR STRESS-STRAIN DATA
C      CALL REGA1(STRS,STRN,IPTS•EOPT,0.*A1•EX,0)
C      IF(IC•EQ.1) TY(IL) = RRO(G12(IL),A1•EX)
C      IF(IC•EQ.1) XM = FX
C      IF(IC•EQ.2) STY(IL) = RRO(F22(IL),A1•EX)
C      IF(IC•EQ.2) XN = EX
C      IF(IC•EQ.3) SCY(IL) = RRO(F22(IL),A1•EX)
C      IF(IC•EQ.3) XN = EX
C      40 CONTINUEF
C      TF(COPT,NIE,1) GO TO 50
C      NO 43 IL=2,LAY
C      TY(IL) = TY(1)
C      STY(IL) = STY(1)
C      SCY(IL) = SCY(1)
C      43 CONTINUE
C      50 CONTINUEF
C      INPUT LOADINGS AND FAILURE CRITERIA
C      INPUT ANALYSIS CONTROL PARAMETERS
C      PRINT INPUT
C      CALL OUTPT1(NST•LAY•IFCN•KSGM)

C      **** INITIAL ASSIGNMENTS ****
C      *          AND          *
C      *          COMPUTATIONS   *
C      **** **** **** **** **** ****
C      ANGLE REDUCTION ROUTINE
C      CALL ANGLE(LAY,TANG)
C      000225 C
C      SWITCH = 0
C      TT = 0.0E0
C      NO 100 T = 1•LAY
C      TT = TT + T(I)
C      100 CONTINUEF
C
C      000236 C
C      UFAIL(1) = 0
C      UFAIL(2) = 0
C      UFAIL(3) = 0
C      AGATN = 0
C      KSG = 1
C      LT1 = LAY
C      N = LT1
C      LP1 = 1,AY + 1
C
C      000237 C
C      000230 C
C      000231 C
C      000232 C
C      000234 C
C
C      000236 C
C      000237 C
C      000240 C
C      000241 C
C      000242 C
C      000243 C
C      000244 C
C      000245 C

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```
000247      LT2 = LAY*2
000250      LT21 = LAY*2+1
000251      LT3 = LAY*3
000252      LM1 = LAY -1
C
000253      DO 105 I=1,LT3
              SG(I,1) = 0.000E 00
              SG(I,1) = 0.0E00
              SF(I) = 1.0E0
              SG(I,1) = 0.0E0
105  CONTINUE
C
000264      DO 107 I = 1,LAY
              S11(I) = 1.0E0/E11(I)
              S12(I) = -V12(I)/E11(I)
              S21(I) = -V21(I)/F22(I)
107  CONTINUE
C
000276      C PRINT INITIAL ELASTIC LAMINATE CONSTANTS
              CALL PROP(SG,EXX,EYY,VXX,GXY,KSGM,KSG,LAY,1)
C
000310      110 CONTINUE
              WSING = .FALSE.
              MSTRING = .FALSE.
              NIT = 0
              TPT = 0
              SG01 = SG11
              SG02 = SG22
              SG03 = SG12
C
              RETURN TO 110 FOR NEXT INCREMENTAL STEP
C
000311      110 CONTINUE
              WSING = .FALSE.
              MSTRING = .FALSE.
              NIT = 0
              TPT = 0
              SG01 = SG11
              SG02 = SG22
              SG03 = SG12
C
000320      DO 111 K = 1,LT3
              DC(K) = 0.0E0
              SG1(K,1) = 0.0F0
000322      DO 111 L=1,LT3
              NB(K,L) = 0.0E0
000323      A(K,L) = 0.0E0
000324
000326
000331
000334
000341
000342
000344
000347
C
              111 CONTINUE
              DO 1115 I=1,N
                  S22(I) = 1.0F0/E22(I)
                  S44(I) = 1.0F0/(4.0E0*G12(I))
1115  CONTINUE
C
              AFTER 2ND INCREMENTATION USE MULTIPLICATIVE FACTOR
              AS INITIAL STRESS SOLUTION ESTIMATE
              IF (KSG.GE.3 .AND. TPT.EQ.0) GO TO 120
000351      112 CONTINUE
              IF (N.EQ.1) LM1=1
              DO 115 I=1,LM1
C
```

```

000365      SNS = SIN(I)
000367      CSS = COS(I)
000370      SN2 = SIN2(I)
000372      CS2 = COS2(I)
000373      C    IF(N.EQ.1) GO TO 113
000375      SNSP = SIN(I+1)
000377      CSSP = COS(I+1)
000400      SN2P = SIN2(I+1)
000402      CS2P = COS2(I+1)
000403      C    113 CONTINUE
000403      A(1,I) = CSS*T(I)
000407      A(1,I+N) = SNS*T(I)
000414      C    A(1,I+2*N) = -SN2*T(I)
000422      C    A(2,I) = SNS*T(I)
000426      A(2,I+N) = CSS*T(I)
000432      C    A(2,I+2*N) = SN2*T(I)
000440      C    A(3,I) = SN2*T(I)/2.0E0
000444      A(3,I+N) = -SN2*T(I)/2.0E0
000451      A(3,I+2*N) = CS2*T(I)
000455      C    IF(N.EQ.1) GO TO 116
000457      C    A(3*I+1,I) = -S11(I)*CSS -S21(I)*SNS
000465      A(3*I+1,I+1) = S11(I+1)*CSSP + S21(I+1)*SNSP
000474      A(3*I+1,I+N) = -S12(I)*CSS -S22(I)*SNS
000503      A(3*I+1,I+2*N) = S12(I+1)*CSSP + S22(I+1)*SNSP
000512      A(3*I+1,I+2*N) = 2.0E0*S544(I)*SN2
000521      A(3*I+1,I+2*N+1) = -2.0E0*S544(I+1)*SN2P
000530      C    A(3*I+2,I) = -S11(I)*SNS -S21(I)*CSS
000536      A(3*I+2,I+1) = S11(I+1)*SNSP + S21(I+1)*CSSP
000545      A(3*I+2,I+N) = -S12(I)*SNS -S22(I)*CSS
000554      A(3*I+2,I+2*N) = S12(I+1)*SNSP + S22(I+1)*CSSP
000563      A(3*I+2,I+2*N+1) = -2.0E0*S544(I)*SN2
000572      C    A(3*I+2,I+2*N+1) = 2.0E0*S544(I+1)*SN2P
000601      C    A(3*I+3,I) = -(S11(I)-S21(I))*SN2/2.0E0
000610      A(3*I+3,I+1) = (S11(I+1)-S21(I+1))*SN2P/2.0E0
000620      A(3*I+3,I+N) = -(S12(I)-S22(I))*SN2/2.0E0
000627      A(3*I+3,I+2*N) = (S12(I+1)-S22(I+1))*SN2P/2.0E0
000636      A(3*I+3,I+2*N+1) = -2.0E0*S544(I)*CS2
000644      C    115 CONTINUE
000653      C    A(1,N) = CSSP*T(N)
000655      A(1,2*N) = SNSP*T(N)
000661      A(1,3*N) = -SN2P*T(N)
000665      A(2,N) = SNSP*T(N)
000672      A(2,2*N) = CSSP*T(N)
000676      A(2,3*N) = SN2P*T(N)
000702      A(3,N) = SN2P*T(N)/2.0E0

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      A(3,2*N) = -SN2P*T(N)/2.0E0
      A(3,3*N) = CS2P*T(N)
000712
000716    116 CONTINUE
000723    IF(MSING) GO TO 117
C
C
C     INVERT MATRIX A
C     CALL INVRTU(A,60,LT3*DET, SFNS , IRANK,1.00E-30)
C
C     CHECK FOR SINGULAR MATRIX
C     TF(IRANK,EQ.,LT3) GO TO 118
      MSING = TRUE.
      WRITE(6,1420) IRANK,DET
      GO TO 117?
000735
000736
000745    117 CONTINUE
      WRITE(6,1425) ((A(K1,L1),L1=1,LT3),K1=1,LT3)
      MSING = FALSE.
      GO TO 999
000746
000756    118 CONTINUE
000770
C
C     INITIAL LOAD VECTOR
      IF (SWITCH.EQ.1) GO TO 119
      SG0(1,1) = S011*TT
      SG0(2,1) = S022*TT
      SG0(3,1) = S012*TT
000771    119 CONTINUE
      CALL MXMULD(A,SG0,SG,60,60,1,LT3,LT3,1)
C
C     RESET STRESS = 0. IF RELATIVE STRESS > 1.0D-06
      CALL RESFT(LT3,SG, RATIO )
      GO TO 126
000777
C
C     (MULTIPLICATIVE FACTOR) X (SOLUTION FROM PREVIOUS INCREMENT)
      120 CONTINUE
      DO 122 I=1,LT3
      SG(I,1) = SF(I)*SGS(I)
000778    122 CONTINUE
      GO TO 126
000779
C
C     RETURN TO 125 FOR NEXT ITERATION STEP
      125 CONTINUE
      NIT = NIT + 1
000780    126 CONTINUE
C     STORE STRESS SOLUTION FOR THIS ITERATION
      DO 127 I=1,LT3
      SG(I,1) = SG(I,1)
      RT(I) = 0.0E 00
000781    127 CONTINUE
C
001023    130 CONTINUE
      DO 130 K=1,LT3
      DO 130 L=1,LT3
      NB(K,L) = 0.0E 00
001024
001025
001026
001027
001028
001029
001030
001031
001032
001033
001034
001035
001036
001037

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```

001042      1305 CONTINUE
C           **** DERIVATIVE MATRIX ****
C           FOR
C           NEWTON-RAPHSON ANALYSIS *
C           **** **** **** **** **** ****
C IF(N.EQ.1) LM=1
001051      NO 151 I=L,LM
C           CALCULATION OF TERMS USED IN FORMATION OF DERIVATIVE MATRIX
C IF(N.EQ.1) GO TO 1308
001053      CALL NRTRM (LAY,SG,F,G,H,I)
001055      CALL NRTRM (LAY,SG,F,G,H,I+1)
001061      1308 CONTINUE
C           SNS = SINS(I)
001067      CSS = COSS(I)
C           SN2 = SIN2(I)
CS2 = COS2(I)
C TF(N.EQ.1) GO TO 131
001071      SNSP = SINS(I+1)
001073      CSSP = COSS(I+1)
SN2P = SIN2(I+1)
CS2P = COS2(I+1)
C 131 CONTINUE
001106      DB(I,1) = CSS*T(I)
001107      DB(I,1+N) = SNS*T(I)
001112      DB(I,1+2*N) = -SN2*T(I)
001117      DB(2,I) = SNS*T(I)
001125      DB(2,I+N) = CSS*T(I)
001131      DB(2,I+2*N) = SN2*T(I)
001135      DB(3,I) = SN2*T(I)/2.
001143      DB(3,I+N) = -SN2*T(I)/2.
001147      DB(3,I+2*N) = CS2*T(I)
001154      IF(N.EQ.1) GO TO 161
C           DB(3*I+1,I) = -F(I,I)
001160      DB(3*I+1,I+1) = F(I,I+1)
001162      DB(3*I+1,I+2) = F(I,I+2)
001167      DB(3*I+1,I+3) = F(I,I+3)
001174      DB(3*I+1,I+4) = F(I,I+4)
001201      DB(3*I+1,I+5+N+1) = F(I,I+5+N+1)
001207      DB(3*I+1,I+2*N) = F(I,I+2*N)
001215      DB(3*I+1,I+2*N+1) = F(I,I+2*N+1)
C           DB(3*I+2,I) = -G(I,I)
001223      DB(3*I+2,I+1) = G(I,I+1)
001231      DB(3*I+2,I+2) = G(I,I+2)
001236      DB(3*I+2,I+3) = G(I,I+3)
001243      DB(3*I+2,I+4) = G(I,I+4)
001251      DB(3*I+2,I+5+N+1) = G(I,I+5+N+1)
001260      DB(3*I+2,I+2*N) = G(I,I+2*N)
C           DB(3*I+3,I) = -H(I,I)
001266      DB(3*I+3,I+1) = H(I,I+1)
001274      DB(3*I+3,I+2) = H(I,I+2)
001301      DB(3*I+3,I+3) = H(I,I+3)
001306      DB(3*I+3,I+4) = H(I,I+4)

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001314 DB(3*I+3,I+2*N) = H(3,I)
001323 DB(3*I+3,I+2*N+1) = H(3,I+1)

001331 C 151 CONTINUE
001334 DB(1,N) = CSSP*T(N)
001340 DB(1,2*N) = SNSP*T(N)
001344 DB(1,3*N) = -SN2P*T(N)
001351 DB(2,N) = SNSP*T(N)
001355 DB(2,2*N) = CSSP*T(N)
001361 DB(2,3*N) = SN2P*T(N)
001365 DB(3,N) = SN2P*T(N)/2.
001371 DB(3,2*N) = -SN2P*T(N)/2.
001375 DB(3,3*N) = CS2P*T(N)
001402 161 CONTINUE
001402 GO TO 167
001402 IF (MSINGN) GO TO 167

C INVERT MATRIX DB,
CALL INVRT(DB,60,LT3,DET, SENS, IRANK,1.00E-30)
C CHECK FOR SINGULAR MATRIX
001412 IF (IRANK.EQ.LT3) GO TO 168
001414 MSINGD = .TRUE.
001415 WRITE(6,1420) IRANK,DET
001424 GO TO 130
001425 167 CONTINUE
001425 WRITE(6,1425) ((DB(K1,L1),L1=1,LT3),K1=1,LT3)
001445 MSINGD = .FALSE.
001446 GO TO 999
001447 168 CONTINUE
C ***** INITIAL VECTOR *****
C * FOR *
C * NEWTON-RAPHSON ANALYSIS *
C *****
C IF (SWITCH.EQ.1) GO TO 173
001451 DC(1) = -S011*TT
001453 DC(2) = -S022*TT
001455 DC(3) = -S012*TT
001456 170 TO 174
001457 173 CONTINUE
001457 DC(1) = -SG0(I+1)
001457 DC(2) = -SG0(2,I)
001457 DC(3) = -SG0(3,I)
001462 174 CONTINUE
C NO 6 I+1 LAY
001466 SNS = SINS(I)
001470 CSS = COSS(I)
001471 SN2 = SIN2(I)
001473 CS2 = COS2(I)
001474 DC(1) = DC(1) + SG(I+1)*CSS*T(I) + SG(LAY+I+1)*SNS*T(I)
DC(1) = SG(P*LAY+I+1)*SN2*T(I)
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001510      DC(2)      = DC(2) + SG(I,1)*SNS*T(I) + SG(LAY+I,1)*CSS*T(I)
1          = SG(2*LAY+I,1)*SN2*T(I)
001524      DC(3)      = DC(3) + SG(I,1)*T(I)*SN2/2. - SG(LAY+I,1)*T(I)*
1          SN2/2. + SG(2*LAY+I,1)*CS2*T(I)
001540      6 CONTINUE

001543      C
          FORM NON-LINEAR COMPLIANCE TERMS S22 AND S44
001544      DO 7 K=1,N
          T12S = (SG(K+2*N,1)/TY(K))**2
001550      IF(SG(K+N,1)=0.0) 1*2,*?
001553      1 TS22S = (SG(K+N,1)/SCY(K))**2
001557      GO TO 3
001557      2 TS22S = (SG(K+N,1)/STY(K))**2
001563      3 S12S = T12S + TS22S
001565      S22(K) = (1.0E0+S12S***((XN-1.0)/2.))/E22(K)
001577      S44(K) = (1.0F0+S12S***((XM-1.0)/2.))/(4.0E0*G12(K))
001612      7 CONTINUE

001614      TF(N,EQ.1) GO TO 5008
001616      DO R K=1,LM1
001617      SNS = SIN5(K)
001621      CSS = COS5(K)
001622      SN2 = SIN2(K)
001624      CS2 = COS2(K)
001625      SNSP = SIN5(K+1)
001627      CSSP = COS5(K+1)
001630      SN2P = SIN2(K+1)
001632      CS2P = COS2(K+1)

001633      NC(3+3*K-2) = -(S11(K)*CSS*S21(K)*SNS)*SG(K,1) -
1          SG(LAY+K,1)*(S12(K)*CSS*S22(K)*SNS) + 2.*S44(K)*SN2*-
2          SG(2*LAY+K,1) + (S11(K+1)*CSSP*S21(K+1)*SNSP) *
3          *SG(K+1,1) + (S12(K+1)*CSSP*S22(K+1)*SNSP) *
4          SG(LAY+K+1,1) - 2.*S44(K+1)*SG(2*LAY+K+1,1)*
5          SN2P + SG(3+3*K-2,1)
1          NC(3+3*K-1) = -(S11(K)*SNS*S21(K)*CSS)*SG(K,1) - (S12(K)*SNS*
2          S22(K)*CSS)*SG(LAY+K,1) - 2.*S44(K)*SN2*-
3          SG(2*LAY+K,1) +
(S11(K+1)*SNSP*S21(K+1)*CSSP)*SG(LAY+K+1,1) + (S12(K+1)*
4          SNSP+S22(K+1)*CSSP)*SG(LAY+K+1,1) + 2.*S44(K+1)*SN2P
5          *SG(2*LAY+K+1,1) + SG(3+3*K-1,1)
001706      DC(3+3*K) = -(S11(K)-S21(K))*SN2*SG(K,1)/2. - (S12(K)-S22(K))*-
1          SN2*SG(LAY+K,1)/2. - 2.*S44(K)*CS2*SG(2*LAY+K,1) +
2          (S11(K+1)-S21(K+1))*SN2P*SG(K+1,1)/2. + (S12(K+1)*
3          S22(K+1))*SN2P*SG(LAY+K+1,1)/2. + 2.*S44(K+1)*CS2P*
4          SG(2*LAY+K+1,1) + SG(3+3*K,1)
002035      8 CONTINUE
002037      500A CONTINU
002037      C
          DO 9 I=1,LT3
002041      DC(I) = -DC(I)
9 CONTINU
002043      C
002045      DO 11 I=1,LT3
002046      DO 11 K=1,LT3

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```

002047 C **** FORM SOLUTION VECTOR ****
C * * * * * FORM SOLUTION VECTOR *
C * * * * * FOR
C * * * * * THIS ITERATION
C * * * * * ****
C
C NO 15 I=1*L3
C SG(I,1) = SG1(I,1) + RT(I)
C 15 CONTINUE
C
C RESET STRESS = 0, IF RELATIVE STRESS > 1.0D-06
C CALL RESET(LT3,SG, RATIO )
C IF (NIT.EQ.0) GO TO 125
C
C CALL CONVR(LAY,SG,SG1,KSG,IRTN)
C 60 TO (495,125,900),IRTN
C
C 495 CONTINUE
C IF (SWITCH.EW.0) GO TO 500
C SG01 = SG0(1,1)/TT
C SG02 = SG0(2,1)/TT
C SG03 = SG0(3,1)/TT
C
C 500 CONTINUE
C
C DO 54n I = 1,LAY
C SNS = SINS(I)
C CSS = CSNS(I)
C SN2 = SINC2(I)
C CS2 = COS2(I)
C
C STRAIN COMPUTATIONS IN FIBER AXES DIRECTIONS
C P11(I) = S11(I)*SG(1,1) + S12(I)*SG(1+N,1)
C T125 = (SG(I+2*N,1)/TY(I))*#2
C IF (SG(I+N,1)**C.0) 4*5*5
C 4 TS225 = SG(I+N,1)/SCY(I))*#2
C
C 60 TO 18
C 5 TS225=(SG(I+N,1))/STY(I))*#2
C 18 S125=S12S+TS225
C P22(I) = S21(I)*SG(I,1) + SG(I+N,1)/E22(I)*(1.0E0+S125
C
C 1 -1*/2*)
C P12(I) = SG(I+2*N,1)/(2.*G12(I))*(1.0E0+S125**((XM-1))
C
C 520 CONTINUE
C EPN(I, *1) = P11(I)
C EPN(I+N,1) = P22(I)
C EPN(I+2*N,1) = P12(I)
C
C STRAIN COMPUTATIONS IN LAMINATE AXES DIRECTIONS
C FP1(I) = P11(I)*CSS + P22(I)*SNS - P12(I)*SN2
C EP22(I) = P11(I)*SNS + P22(I)*CSS + P12(I)*SN2
C
C 1002221
C 002211
C 002213
C 002216
C
C 1002222
C

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002235      C      FP12(I) = (P11(I)-P22(I))*SN2/2.E0 + P12(I)*CS2
002243      C      540 CONTINUE
002244      C      IF (AGAIN.EQ.1) GO TO 752
002250      C      IF (SWITCH.EQ.0) GO TO 610
002251      C      SWITCH = 0
002251      C      IPT = 1
002252      C      GO TO 730
C
C      *****
C      * LAMINATE FAILURE TESTS *
C      *****
C      610 CONTINUE
C      CALL LAMTST(LAY,SG,SGS,PN,PS,KSGM,IFCN,UFAIL,FAC,SWITCH)
C
C      *****
C      * OUTPUT PER *
C      * LOAD INCREMENT *
C      *****
C      730 CONTINUE
002266      C      WRITE(6,1525)
002272      C      WRITE(6,1527) SG01
002300      C      WRITE(6,1528) SG02
002306      C      WRITE(6,1529) SG03
002314      C      WRITE(6,1735) NIT
002322      C      WRITE(6,1536)
002324      C      WRITE(6,1537)
002332      C      WRITE(6,1538)
002336      C      DO 750 I = 1,LAY
002340      C      EP12(I)=EP12(I)*2.
002342      C      WRITE(6,1550) 1.*SG(I,1)*SG(I+N,1)*SG(I+2*N,1)*
1          EP11(I)*EP22(I)*EP12(I)*P11(I)*P22(I),P12(I)
002375      C      FP12(I)=FP12(I)/2.
002400      C      750 CONTINUE
002412      C      IF (IPT.EQ.1) WRITE(6,1990)
002407      C      IF (IPT.EQ.1) AGAIN=1
002412      C      IF (IPT.EQ.1) GO TO 110
C
C      COMPUTE TNELASTIC MATERIAL PROPERTIES AND RETAIN AS FUNCTION OF INCREMENT
002413      C      752 CONTINUE
002413      C      AGAIN = 0
002414      C      CALL PROP(SG,EXX,EYY,VXY,VYY,GXY,KSGM,KSGL,LAY,2)
002426      C      NO 755 I=1,LAY
002430      C      STXX(I*KSG) = SG(I      *1)
002434      C      STYY(I*KSG) = SG(I+N,1)
002441      C      STXY(I*KSG) = SG(I+2*N,1)
002446      C      755 CONTINUE
C
C      CHECK FOR LAMINATE FAILURE, IF FAILURE HAS OCCURED INTERPOLATE LOADS TO
C      FAILURE POINT AND REEVALUATE
C      IF (SWITCH.EQ.0) GO TO 758
002450      C      WRITE(6,1555)
002451      C      WRITE(6,1560)
002455      C      SG0(1,1) = ((S01)-SM11) + FAC*SM11)*TT
002461      C      SG0(2,1) = ((S02)-SM22) + FAC*SM22)*TT
002466      C

```

RUN VERSION 2.3 --PSR LFVEL 363--

MAIN

07/23/74

```
002472      SGO(3,1) = ((S012-SM12) + FAC*SM12)*TT
002477      GO TO 110
002477      75B CONTINUE
C          C   CHECK FOR INCREMENTATION LIMIT
C          C   IF (KSGM=KSG) 790,790,760
C          C   *****
C          C   ***** INCREMENTATION *****
C          C   ***** ESTIMATE *****
C          C   *****
C          C   760  CONTINUE
C          C   GO TO (762,766), INMT
C          C   RATIO OF PREVIOUS SOLUTIONS
C          C   762  CONTINUE
C          DO 765 I=1,LT3
C          IF (KSG.EQ.1) GO TO 770
C          IF (SGS(1).EQ.0.0E0) GO TO 763
C          SF(1) = SG(I,1)/SGS(1)
C          GO TO 745
C          763  CONTINUE
C          SF(1) = 1.0E0
C          765  CONTINUE
C          SF(1) = 1.0E0
C          GO TO 770
C          766  CONTINUE
C          DO 768 I=1,LT3
C          IF (KSG.LT.2) GO TO 767
C          TF(SG(I,1)).EQ.0.0E0) GO TO 767
C          VKSG = KSG + 1
C          CONS = VKSG*(VKSG-2)/(VKSG-1)**2
C          SF(1) = 1.0E0 + CONS*(SG(I,1)-SGS(1))/SG(I,1)
C          GO TO 768
C          767  CONTINUE
C          SF(1) = 1.0E0
C          768  CONTINUE
C          C   STORE STRESS AND STRAIN VALUES
C          C   770  CONTINUE
C          DO 775 I = 1,LAY
C          SGS(I) = SG(I      *1)
C          SGS(I+N) = SG(I+N*1)
C          SGS(I+2*N) = SG(I+2*N*1)
C          FPS1(I,I) = EP11(I)
C          EPS22(I) = EP22(I)
C          EPS12(I) = EP12(I)
C          PS(I) = P11(I)
C          PS(I+N) = P22(I)
C          PS(I+2*N) = P12(I)
C          775  CONTINUE
C          C   INCREMENT APPLIED LOADING
C          KSG = KSG + 1
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```

      SUBROUTINE HEADER
      C   ROUTINE HEADER PRINTS HEADER INFORMATION FOR NOLIN V2 MP
      C
      C   REAL          MESSAG(100)
      C   RETRIEVF JULIAN DATE FROM THE OPERATING SYSTEM.....
      C   DATE=0
      C   READ IN 5 CARD PROGRAM IDENTIFICATION
      C   READ(5,200) (MESSAG(I), I=1,100)
      C   200 FORMAT(20A4)
      C   WRITE OUT TITLE, DATE, AND PROGRAM IDENTIFICATION
      C   WRITE(6,000) DATE, (MESSAG(J), J=1,100)
      000002  C   000002 FORMAT(1H1, // *41X, *41(***) *3(/ *41X,***,39X,****) * /,
      *           *41X,***, *14X, *NONLINEAR, *16X,***, / *41X,***,39X,****) * /,
      *           *41X,***, *8X, *THERMOELASTIC ANALYSIS, *9X,***, /,
      *           *41X,***, *39X, ***, / *41X,***,1BX,**OF*,19X,***, /,
      *           *41X,***, *39X, ***, / *41X,***, / *41X,***,10X, *FIBRUS COMPOSITES*,*
      *           *11X,***, * / *41X,***,39X,***, / *41X,***,17X, *AND*,19X,***, /,
      *           *41X,***, *39X, ***, / *41X,***, 6X,
      *           *NON-HOMOGENEOUS LAMINATES, *8X,***,3(/ *41X,***,39X,****) *,
      *           /*41X, *41(***) * /,
      *           /*21X, *, VERSION 2, MOD 3 (MAY 74)*,
      *           /*21X, *, DATE * , A10 * //,21X,
      *           * , PROGRAM IDENTIFICATION*, //,5(21X,20A4,*), //, /,
      C
      C   RETURN
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      SUBROUTINE MATCRL (NSR)
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     1          S12(20),S11C(20),S22C(20),EP11T(20),EP11C(20),
     2          *EP22C(20),E11(20),E22(20),GAMA(20),V12(20),
     3          T(20),A12(20),V21(20),TE11(20),TE22(20),TG12(20),
     4          *TV12(20),TA12(20),TSY(20),TSCY(20),TY(20),TY(20),
     5          STY(20),SCY(20),EP11(20),EP22(20),EP12(20),EP12(20),
     6          POINTS(50,6,20),EPS11(50,20),EPS22(50,20),EPS12(50,20),
     7          TEPS11(50,20),TEPS22(50,20),TEPS12(50,20),
     8          SIG11(50,20),SIG22(50,20),SIG12(50,20),A11(20),A22(20),
     9          A44(20),B1(20),B2(20),S11(20),S22(20),S12(20),
      COMMON /SET01/ E11,E22,V12,V21,612
      COMMON /SET02/ TT,THICK,THETA
      COMMON /SET03/ EP11,EP22,EP12
      COMMON /SET04/ S011,S022,S012,S011,SM22,SM12
      COMMON /SET05/ ULT,STIFF
      COMMON /SET08/ S11,S22,S12,S21
      COMMON /SET09/ NLAY,EOPT,COP1,IFCN,KSGM,INMT,RATIO,SENS
      COMMON /SET10/ STY,SCY,TY,XM,XN
      COMMON /SET11/ EPS,UPAD,NIT,IT,SMLT
      COMMON /SET14/ A11,A22,A44,A12,B1,B2
      COMMON /SET15/ POINTS,IPRINT,IOP,IP1S,LUP
      COMMON /SET16/ MATYPE,S11T,S11C,S22T,S22C,EP11T,EP11C,
     1          EP22T,EP22C,GAMA,SIG11,SIG22,SIG12
      COMMON /SET17/ TE11,TE22,TE12,TV12,TA12,TSCY,TTY
      INTEGER EOFT,COPT
      NAMELIST /DATA/NLAY,E11,E22,V12,G12,THICK,THETA,TOPI,
     1          STY,SCY,XM,XN,EUPT,COPT,IPTS,IPRINT,S011,S022,S012,
     2          IFCN,STIFF,A12,KSGM,SMLT,IT,EPS,UPAD,INMT,RATIO,SENS,
     3          S11T,S22T,S12,S11C,S22C,EP11T,EP22T,EP11C,EP22C,
     4          GAMA,SIG11,SIG22,SIG12,EP11,EP22,EP12,MATTYPE
      NSR=0
      READ(5,1)ATA
      IF (EOF,5) 424,425
 425  DO 10 I=1,20
      TE11(I)=E11(I)
      TE22(I)=E22(I)
      TG12(I)=G12(I)
      TV12(I)=V12(I)
      TA12(I)=A12(I)
      TSY(I)=STY(I)
      TSCY(I)=SCY(I)
      TSCY(I)=SCY(I)
 10    TTY(I)=TY(I)
      DO 200 I=1,20
      M=MATYPF(I)
      F11(I)=TE11(M)
      F22(I)=TE22(M)
      G12(I)=TG12(M)
      V12(I)=TV12(M)
      A12(I)=TA12(M)
      STY(I)=TSCY(M)
      SCY(I)=TSCY(M)
 200  NSR=0
      END

```

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MATCRL

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```
    TY(I) = TTY(M)
    ULT(1,1,I) = S11T(M)
    ULT(1,2,I) = S11C(M)
    ULT(2,1,I) = S12T(M)
    ULT(2,2,I) = S12C(M)
    ULT(3,1,I) = S12(M)
    ULT(3,2,I) = S12(M)
    ULT(4,1,I) = EP11T(M)
    ULT(4,2,I) = EP11C(M)
    ULT(5,1,I) = EP22T(M)
    ULT(5,2,I) = EP22C(M)
    ULT(6,1,I) = GAMA(M)
    ULT(6,2,I) = GAMA(M)
DO 200 J = 1, IPTS
  POINTS(J,J,I) = SIG11(J,M)
  POINTS(J,2,I) = EPS11(J,M)
  POINTS(J,3,I) = SIG12(J,M)
  POINTS(J,4,I) = EPS12(J,M)
  POINTS(J,5,I) = SIG12(J,M)
  POINTS(J,6,I) = EPS12(J,M)
200  RETURN
424  NSP=1
      RETURN
      END
100171
100172
100173
100174
```



```

00247 WRITE(6,1526) S022,S022
00257 WRITE(6,1528) S012,S012
00267 TFN = 2*IFCN
00273 TST = IFN-
00275 WRITE(6,1530) (HDFFAIL(IF),IF=IST,IFN)
00276 IF(IFCN.NE.2) WRITE(6,1532)
00277 IF(IFCN.NE.4) WRITE(6,1532)
00278 IF(IFCN.EQ.2).OR.(IFCN.EQ.4) IFS#=1
00279 IF(IFCN.EQ.2).OR.(IFCN.EQ.4) WRITE(6,1533)
00280 IF(IFCN.FQ.2) IFS#=4
00281 DO 90 IL=1,LAY
00282 CONTINUE
00283 IFE = IFS+2
00284 WRITE(6,1534) IL,(ULT(ID,IM,IL),ID=IFN,IFE),IM=1*2)
00285 IF(IFCN.NE.4) GO TO 90
00286 IF(IFCN.EQ.1) IFS#=4
00287 IF(IFCN.EQ.3) GO TO 85
00288 TFS = 1
00289 CONTINUE
00290 IF(IFCN.EQ.1).OR.(IFCN.EQ.2) GO TO 110
00291 WRITE(6,1535)
00292 DO 95 IL=1,LAY
00293 WRITE(6,1536) IL,A12(IL)
00294 CONTINUE
00295 CONTINUE
00296 WRITE(6,1538) STIFF
00297 WRITE(6,1540)
00298 WRITE(6,1544) IT
00299 WRITE(6,1546) EPS
00300 WRITE(6,1548) UPBD

C C
00301 1507 FORMAT(//,* DATA INPUT POINTS FOR CURVE FIT-*/)
00302 1508 FORMAT(1H,50X,*LAMINATE*,14,/50X,12(*,*))
00303 1509 FORMAT(//,* NUMBER OF LAYERS = * 12)
00304 1510 FORMAT(//,* LAYER THE TA*,6X,*T*,13X,*E11*, 9X,*E22*,*
00305 1511 1513 FORMAT(//,* V12*, 9X,*V21*, 9X,*G12*,8X,*SGT Y*,8X,*SGC Y*)
00306 * 1515 FORMAT(14*3X,F6.2,2X,E11.4,X,8(1X,E11.4))
00307 1516 FORMAT(//,* EXTERNALLY APPLIED STRESS*,50X,27(*)
00308 1517 FORMAT(//,* INCREMENT M = * E12.5)
00309 1518 FORMAT(//,* EXPONENT N = * E12.5)
00310 1520 FORMAT(//,*30X,*INITIAL*,18X,*STRESS*, 42X,*NO. OF*
00311 * /32X,*STRESS*,17X,*INCREMENT*,37X,*INCREMENT*
00312 1524 FORMAT(15X,*56 XX*,4X,E15.5,11X,E15.5, 37X,15),
00313 1526 FORMAT(15X,*56 YY*,4X,E15.5,11X,E15.5)
00314 1528 FORMAT(15X,*56 ZZ*,4X,E15.5,11X,E15.5)
00315 1530 FORMAT(//50X,*LAMINA FAILURE CRITERIA*,/50X,23(*,*))
00316 * /52X,2A10//16X*AYER*,18X,*LL*23X,*TT*,25X
00317 * 1532 FORMAT( 25X,*ULT. STRESS*)
00318 1533 FORMAT(25X,*ULT. STRAIN*/25X,*NOTE* ALL STRAINS ARE
00319 * ING COMPONENTS*)
00320 * 1534 FORMAT(1/16X,I2, 4X,*TENS., 4X,(E15.5,10X),*22X,*CO*
00321 * 4X,(E15.5,10X),*22X,*CO*
00322 1535 FORMAT(16X,I2,*AYER*,20X,*QUADRATIC INTERACTION TERM
00323 1536 FORMAT(16X,I2,*27X*,E15.5,

```

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```
      1538 FORMAT (15X,*STIFFNESS = *,F15.5)
J0511 1540 FORMAT (15X,*CONTROL PARAMETERS*,/50X,18(*,*))
J0511 1544 FORMAT (15X,*MAX. NO. OF INTEGRATIONS = *,I5)
J0511 1546 FORMAT (15X,*CONVERGENCE CRITERIA = *,E15.5)
J0511 1548 FORMAT (15X,*DIVERGENCE CRITERIA = *,E15.5)
J0511 1553 FORMAT (3X,RE14.5/3X,2E14.5//)
C
      RETURN
      END
```

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OUTPT1

```

SUBROUTINE PROP(SG,EXX,EYY,VXY,VYY,GXY,KSGM,ILD,LAY,LPROP)
C ROUTINE PROP COMPUTES INITIAL LAMINATE CONSTANTS (LPROP=1)
C OR NONLINEAR LAMINATE PROPERTIES AS FUNCTION OF RESULTANT STRESS (LPROP=2)
C
C CSUM(I,J)           ! THICKNESS WEIGHTED SUM OF LAYER STIFFNESSES
C HEL                 ! IN LAMINATE COORDINATES
C HET                 ! LONGITUDINAL YOUNG'S MODULUS OF LAMINATE
C NULT                ! TRANSVERSE YOUNG'S MODULUS OF LAMINATE
C NULT                ! POTSSON RATIO IN LONG.-TRANS.
C NULT                ! POTSSON RATIO IN TRANS.-LONG.
C HGLT                ! IN-PLANE SHEAR MODULUS OF LAMINATE
C
C *****
C * VARIABLE DICTIONARY *
C
C
C 0015      DIMENSION   TNS(3*3),CMT(3*3),TMP(3*3),CSUM(3*3),
C             FXX(KSGM),FYY(KSGM),VXY(KSGM),VYY(KSGM),GXY(KSGM)
C             T(20)*SG(60,1),IANG(20)
C             DIMENSION   H(25),TH(25),A(3*3)
C             REAL IANG ,NULT,NULT
C             EQUIVALENCE (CSUM(1),A(1))
C             COMMON /SET02/ TT,T,IANG
C
C
C 0015      INITIALIZE
C             DO 30 I=1,3
C             DO 30 J=1,3
C             CSUM(I,J) = 0.00
C 30 CONTINUEF
C
C 0022      GO TO (50,75), LPROP
C 50 CONTINUEF
C             T0 = TT/2.
C             H0 = -T0
C 0034      TSUM = T(1)
C 0036      TH(1) = T(1)
C 0037      H(1) = H0 + T(1)
C 0041      H(1) = H0 + T(1)
C 0042      H(1) = H0 + T(1)
C 0044      DO 62 K=2,LAY
C             TSUM = TSUM + T(K)
C 0045      H(K) = H0 + TSUM
C 0047      TH(K) = H(K) - H(K-1)
C 0052      62 CONTINUEF
C 0055      GO TO 90
C 0057      75 CONTINUEF
C             DO 85 K=1,LAY
C             TH(K) = T(K)/TT
C 0061      85 CONTINUEF
C             90 CONTINUEF
C
C 0066      GENERATE SIMILARITY MATRIX OF CMT FOR EACH LAYER
C             CSIM = TNS*(-1)*CMT*TNS
C
C 0066      DO 150 K=1,LAY

```

```

0070 CALL TRANS(TNS,K)
0072 CALL CMATX(CMT,SG,LAY,K,LPROP)
0103 CALL MXMUL(CMT,TNS,TMP,3,3,3,3,3)
0114 CALL INVPD(TNS,3,3,DET,1.0F-12,IRANK,1.0E-30)
0123 CALL MXMUL(TNS,TMP,CMT,3,3,3,3,3,3,3)
0130 DO 110 K1 =1,3
0141 DO 110 KJ =1,3
0142 CSUM(KI,KJ)=CSUM(KI,KJ)+CMT(KI,KJ)*TH(K)
0152 110 CONTINUE
0156 150 CONTINUE

C      INVERT RESULTANT MATRIX
C      CALL INVRTD(CSUM,3,3,DET,1.0E-12,IRANK,1.0E-30)

0161      C      60' TO (175,500) • LPROP
0201 175 CONTINUE
0201      HEL = 1. / (A(1,1)*TT)
0204      HET = 1. / (A(2,2)*TT)
0207      NULT = -(A(1,2)/A(1,1))
0211      NULT = -(A(1,2)/A(2,2))
0213      HGLT = 1. / (2.*A(3,3)*TT)
0216      WRITE(6,1510)
0222      WRITE(6,1522) HEL
0230      WRITE(6,1524) HET
0236      WRITE(6,1526) NULT
0244      WRITE(6,1528) NULT
0252      WRITE(6,1532) HGLT
0260      WRITE(6,1560)
0264      RETURN

C      500 CONTINUE
C      COMPUTE NONLINEAR PROPERTIES AS FUNCTION OF STRESS
0265      FXX(ILD) = 1./CSUM(1,1)
0274      FYY(ILD) = 1./CSUM(2,2)
0276      VXY(ILD) = -CSUM(1,2)/CSUM(1,1)
0300      VYX(ILD) = -CSUM(1,2)/CSUM(2,2)
0303      GXY(ILD) = 1./CSUM(3,3)
0305      RETURN

C      1510 FORMAT (//45X,*PLAMINATE CONSTANTS (STRESS=STRAIN)*,45X,36(*+*))
0305      1522 FORMAT ( /48X,*EXX = *,E15.5)
0305      1524 FORMAT ( 48X,*EYY = *,E15.5)
0305      1526 FORMAT ( 48X,*VYX = *,E15.5)
0305      1528 FORMAT ( 48X,*VXY = *,E15.5)
0305      1532 FORMAT ( 48X,*GXY = *,E15.5)
0305      1560 FORMAT (1H1,50X,*APPLIED STRESS ANALYSIS*/50X,22(*+*))
0305      FND

```

```

      C          SUBROUTINE TRANSIT,I)
      C          ROUTINE TRANS COMPUTES TRANSFORMATION MATRIX
      C          DIMENSION T(3,3),SIN2(20),COS2(20),SINS,COS5
      C          COMMON /SET06/ SIN2,COS2,SINS,COS5
      0005      C          T(1,1) = COS5(I)
      0006          T(2,2) = COS5(I)
      0010          T(1,2) = SINS(I)
      0011          T(2,1) = SINS(I)
      0013          T(1,3) = SIN2(I)
      0014          T(3,1) = -SIN2(I)/2.
      0017          T(3,2) = SIN2(I)/2.
      0020          T(2,3) = -SIN2(I)
      0022          T(3,3) = COS5(I)-SINS(I)

      0024      C          RETURN
      0025      END

```

```
SUBROUTINE CMATX(C,SG,N,I,LPROP)
C      ROUTINE CMATX COMPUTES C MATRIX
C
0010      COMMON /SET01/ E11,E22,V12,V21,G12
0010      COMMON /SET10/ STY,SCY,TY,XM,XN
0010      DIMENSION E11(20),E22(20),V12(20),V21(20),G12(20),
0010                  SCY(20),STY(20),TY(20)
0010      DIMENSION SG(60,1),C(3,3)
C
0010      DENOM = 1.0-V12(I)*V21(I)
0014      C(1,1) = E11(I)/DENOM
0016      C(2,2) = E22(I)/DENOM
0017      TF(LPROP.EQ.1) C(3,3) = 2.*G12(I)
0023      TF(LPROP.EQ.2) C(3,3) = G12(I)/(1.0+(SG(I+2*N,1)/TY(I))*#?)
0033      C(1,2) = V12(I)*E22(I)/DENOM
0037      C(2,1) = C(1,2)
0041      C(1,3) = 0.0
0042      C(2,3) = 0.0
0043      C(3,1) = 0.0
0044      C(3,2) = 0.0
0045      C
      RETURN
0045      END
```

SUBROUTINE REGAI(X,Y,IPTS,OPT,A0,A1,M,IPRT)

C ROUTINE REGAI PERFORMS LEAST-SQUARES CURVE-FIT TO
 C GEOMETRIC CURVE OF FORM: Y = A0 + A1*X**M

* VARIABLE DICTIONARY *

C OPT = 1: DETERMINE A1 + M. IPRI = 0: DO NOT PRINT RESULTS
 C = 2: DETERMINE M = 1: PRINT RESULTS
 C = 3: DETERMINE A1

A0: INTERCEPT (PASSED TO SUBROUTINE)

A1: COEFFICIENT (PASSED TO/OR DETERMINED BY SUBROUTINE)
 M: EXPONENT (PASSED TO/OR DETERMINED BY SUBROUTINE)

```
0013      INTEGER          OPT
          REAL             M
          DIMENSION        X(IPTS),Y(IPTS),OPTION(3)
          EQUIVALENCE      (SX,SNUM)*(SY,SDEN)
          DATA            OPTION/10H A1 AND M*10H      M ONLY.
                           10H   A1 ONLY/
          *
```

0013 C N=IPTS

C INITIALIZE PARTIAL SUMS TO ZERO

```
0014      SX = 0.0
0015      SX2 = 0.0
0016      SY = 0.0
0017      SY2 = 0.0
0020      SXY = 0.0
0021      NOLET = 0
```

C CHOSE APPROPRIATE CURVE-FIT OPTION
 GO TO (50,250,500),OPT

0022 C FIT M AND A1

50 CONTINUE
 DO 100 I = 1,N
 DELETE DATA POINTS YIELDING NEGATIVE ARGUMENTS

C CONVERT TO LOG FORM
 IF ((Y(I)-A0).LE.1.E-20) GO TO A0

XP = ALOG(X(I))

YP = ALOG(Y(I)-A0)

COMPUTE INTERMEDIATE SUMS, SUM SQUARES, AND CROSS PRODUCT SUMS

```
10057      SX = SX + XP
10061      SX2 = SX2 + XP**2
10063      SY = SY + YP
10065      SY2 = SY2 + YP**2
10067      SXY = SXY + XP*YP
10071      GO TO 100
10072      80 CONTINUE
```

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REGA1

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```
10072      NODELET = NODELEFT + 1
10074      100 CONTINUE
10077      C N = N - NODELET
          C COMPUTE REGRESSION EQUATION PARAMETERS
10100      M = (SX - SX*SY/N)/(SX2 - SX**2/N)
10111      A1 = EXP(SY/N - M*SX/N)
          C COMPUTE CORRELATION COEFFICIENT (ARS. VAL.)
10123      R = (N*SXY-SX*SY)/SQRT((N*Sx2-SX**2)*(N*SY2-SY**2))
10143      R = ABS(R)
          GO TO 800
10144      C
          C FIT M ONLY
10150      250 CONTINUE
          GO TO 800
10150      C
          C FIT A1 ONLY
10151      500 CONTINUE
10151      NO 550 I=1,N
          YP = Y(I)-A0
10153      XP = X(I)
10156      SNUM = SNUM + YP*XP**M
10160      SDEN = SDEN + XP**I*(2.*M)
10166      550 CONTINUE
10175      A1 = SNUM/SDEN
10177      R = 1.
10201      C
          C PRINT OPTIONS
10200      800 CONTINUE
          TF(1)PRT.FQ.0) RETURN
          WRITE(6,1500)
          WRITE(6,1510) OPTION(OPT)
          WRITE(6,1515) R
10225      WRITE(6,1520) A0
10233      WRITE(6,1524) A1
10245      WRITE(6,1528) M
10257      C
          IF(NODELET.NE.0) WRITE(6,1810) NODELET
          C
10265      C
          C 1500 FORMAT (1H1,///49X,*LEAST SQUARES REGRESSION ANALYSIS OF FORM//,
          *   60X,*Y = A0 + A1*X.+M*////)
10303      1510 FORMAT (50X,*FIT PARAMETERS.*A10)
10303      1515 FORMAT (50X,*CORFLAT COEFFICIENT OF LOG CURVE = *,F6.2//)
10303      1520 FORMAT (50X,*A0 = *.1PE15.5)
10303      1524 FORMAT (50X,*A1 = *.1PE15.5)
10303      1528 FORMAT (50X,* M = *.1PE15.5)
10303      1810 FORMAT (1H1,10X,*CURVE-FIT WARNING*/25X,15,
          *   * DATA POINTS YIELD NEGATIVE LNG ARGUMENTS AND*,*
          *   * HAVE BEEN DELETED*,*
          C
          RETURN
        END
10303
10304
```

SUBROUTINE ANGLE(LAY,IANG)

```
C ROUTINE ANGLE REDUCES ANGLES TO VALUES BETWEEN 0 AND PI/4 FOR
C COMPUTING SIN AND COS
C
10005      REAL IANG,IAVAL,IANG2
10005      DIMENSION SINS(20),COS(20),SIN2,COS2,SINS,COS2
10005      COMMON /SET06/ SIN2,COS2,SINS,COS2
10005      DO 72 I = 1,LAY
10006      TANG2 = 2*IANG(I)
10011      ANG   = TANG(I)
10012      ANG2  = TANG2
10014      RAD   = ANG /57.295779513D0
10027      RAD2  = ANG2/57.295779513D0
10041      IAVAL = ABS(IANG(I))
10043      IF (IAVAL.EQ.0.0) GO TO 66
10045      IF (IAVAL.NE.90.0) GO TO 62
10047      SINS(I) = COS(0.0E0)**2
10052      COS2(I) = SIN(0.0E0)**2
10056      SIN2(I) = SIN(0.0E0)
10062      COS2(I) = -COS(0.0E0)
10066      GO TO 72
10070      62 CONTINUE
10070      SGN = IANG(I)/IAVAL
10072      IF (IAVAL.NE.45.0) GO TO 64
10075      SIN2(I) = COS(0.0E0)*SGN
10101      COS2(I) = SIN(0.0E0)
10104      GO TO 68
10106      64 CONTINUE
10106      IF (IAVAL.LT.45.0) GO TO 66
10111      RDA = (2.*IAVAL-90.)/57.295779513
10114      SIN2(I) = SGN* COS(SGN*RDA)
10122      COS2(I) = -SGN* SIN(SGN*RDA)
10130      GO TO 68
10132      66 CONTINUE
10132      SIN2(I) = SIN(RAD2)
10136      COS2(I) = COS(RAD2)
10142      68 CONTINUE
10142      SINS(I) = SIN(RAD)**2
10146      COS2(I) = COS(RAD)**2
10152      72 CONTINUE
10156      RETURN
10156      END
```

```

      SUBROUTINE MXMULD(A,B,C,NROWA,NCOLA,NCOLB,MA,NA,NB)
      ROUTINE MXMULD MULTIPLIES TWO MATRICES (A + B), STORES RESULT IN C
      DIMENSION A(NROWA*NCOLA),B(NCOLA*NCOLB),C(NROWA*NCOLB)
      REAL A,B,C,X
      DO 20 I=1,MA
      DO 20 J=1,NB
      X=0.
      DO 10 K=1,NA
      10 X=X+A(I,K)*B(K,J)
      20 C(I,J)=X
      RETURN
      END

```

SUBROUTINE INVRTD(A,NDIM,N,DETA,EPS,IRANK,UNDER)
 C ROUTINE INVRTD INVERTS AN N X N MATRIX USING GAUSS-JORDAN
 C ELIMINATION METHOD

* VARIABLE DICTIONARY *

```

C A(N,N)          ! MATRIX TO BE INVERTED PASSED, INVERSE RETURNED
C NDIM            ! UPPER LIMIT TO MATRIX DIMENSION
C N              ! DIMENSION OF MATRIX
C IRANK           ! RANK OF MATRIX
C DETA            ! DETERMINANT OF MATRIX
C EPS             ! ADJUSTABLE TOLERANCE FACTOR COMPARED TO
C UNDER           ! VALUE OF PIVOTAL ELEMENT DURING INVERSION
C                   ! UNDERFLOW LIMIT (CHECK ON COMPUTED VAR.)
```

```

00012      DIMENSION A(NDIM,NDIM)
00012      INTEGER IR(60),IC(60),R,S
00012      C CHECK MATRIX ELEMENTS FOR UNDERFLOW POSSIBILITIES
00012      DO 5 I=1,N
00013      DO 5 J=1,N
00014      IF( ABS(A(I,J)) .LT. UNDER) A(I,J) = 0.0E 00
00027      5 CONTINUE
00034      DETA=1.
00035      SUM=0.
00036      DO 10 I = 1,N
00037      DO 10 J = 1,N
00040      10 SUM=SUM+A(I,J)**2
00052      SUM= SQRT(SUM)
00054      DMA = N**2
00061      RMS=SUM/DMA
00063      TOL=EPS*RMS
00064      DO 20 I = 1,N
00066      IR(I)=0
00067      20 IC(I)=0
00072      S=0
00073      R = N
00074      30 I=0
00075      J=0
00076      TEST=0.0
00077      DO 50 K = 1,N
00100      IF( IR(K) .NE. 0) GO TO 50
00102      DO 40 L = 1,N
00103      IF( IC(L) .NE. 0) GO TO 40
00105      X= ABS(A(K,L))
00112      IF( X .LT. TEST) GO TO 40
00114      T=K
00116      J=L
00117      TEST=X
00120      40 CONTINUE
00123      50 CONTINUE
00126      PIV=A(I,J)
```

```

00133 IF( ABS(DETA)*LT.UNDER) DETA = 0.00E 00
00137 DETA=PIV*DETA
00141 TF( ABS(PIV) .LE. TOL) GO TO 150
00143 TR(I)=J
00145 TC(J)=I
00146 PIV = 1.0E0/PIV
00150 A(I,J)=PIV
00153 DO 60 K = 1,N
00155 60 TF(K.NE.J)A(I,K)=A(I,K)*PIV
00156 DO 90 K = 1,N
00167 IF( K.EQ.I) GO TO 90
00171 PIV1 = A(K,J)
00175 70 DO 80 L = 1,N
00177 IF( ABS(PIV1).LT.UNDER) PIV1=0.0E 00
00203 IF( ABS(A(I,L)).LT.UNDER) A(I,L) = 0.00E 00
00217 80 IF(L.NE.J)A(K,L)=A(K,L)-PIV1*A(I,L)
00235 90 CONTINUE
00240 DO 100 K = 1,N
00241 100 IF(K.NE.I)A(K,J)=-PIV*A(K,J)
00253 S=S+1
00254 TF(S,LT,R)GO TO 30
00256 110 DO 140 I = 1,N
00260 K=IC(I)
00262 M=IR(I)
00263 IF( K.EQ.I)GO TO 140
00265 DETA=DETA
00266 DO 120 L = 1,N
00267 TEMPEA(K,L)
00273 A(K,L)=A(I,L)
00302 120 A(I,L)=TEMP
00306 DO 130 L = 1,N
00307 TEMPEA(L,M)
00314 A(L,M)=A(I,I)
00322 130 A(L,I)=TEMP
00330 IC(M)=K
00332 TR(K)=M
00333 140 CONTINUE
00336 150 IRANK=S
00337 RETURN
00340 FND

```

```

R12D0035 R12D0036
R12D0036 R12D0037
R12D0037 R12D0038
R12D0038 R12D0039
R12D0039 R12D0040
R12D0040 R12D0041
R12D0041 R12D0042
R12D0042 R12D0043
R12D0043 R12D0044
R12D0044 R12D0045
R12D0045 R12D0046
R12D0046 R12D0047
R12D0047 R12D0048
R12D0048 R12D0049
R12D0049 R12D0050
R12D0050 R12D0051
R12D0051 R12D0052
R12D0052 R12D0053
R12D0053 R12D0054
R12D0054 R12D0055
R12D0055 R12D0056
R12D0056 R12D0057
R12D0057 R12D0058
R12D0058 R12D0059
R12D0059 R12D0060
R12D0060 R12D0061
R12D0061 R12D0062
R12D0062 R12D0063
R12D0063 R12D0064
R12D0064 R12D0065
R12D0065 R12D0066
R12D0066 R12D0067
R12D0067 R12D0068
R12D0068 R12D0069
R12D0069 R12D0070

```

SUBROUTINE NRTRM(LAY,SG,F,G,H,I)

C ROUTINE NRTRM COMPUTES ELEMENTS OF DERIVATIVE MATRIX IN
 C NEWTON-RAPHSON ANALYSIS

```

00011      REAL          SG(60,1)
00011      REAL          E11(20),E22(20),V12(20),V21(20),G12(20),
00011      1 DIMENSION   SCY(20),STY(20),TY(20)
00011      1           S11(20),S12(20),S21(20),S22(20),
00011      2           SINS(20),COS(20),SIN2(20),COS2(20),
00011      COMMON        /SET01/ E11,E22,V12,V21,G12,
00011      COMMON        /SET06/ SIN2,COS2,SINS,COS2
00011      COMMON        /SET08/ S11,S22,S12,S21
00011      COMMON        /SET10/ STY,SCY,TY,XM,XN
00011      C
00011      N = LAY
00012      T125 = (SG(I+2*N,1)/TY(I))**2
00016      T12D = SG(I+2*N,1)/TY(I) **2
00022      T225 = (SG(I+N,1)/TY(I))**2
00025      T22D = SG(I+N,1)/TY(I) **2
00031      C12T = SG(I+2*N,1)*SG(I+N,1)/TY(I)**2
00037      IF(SG(I+N,1)= 0.0) 1,2,2
00043      1 VAL = SCY(I)*1.0E-60
00046      1 RAT=SG(I+2*N,1)*SG(I+N,1)/SCY(I)
00054      VAL= ABS(VAL)
00056      RAT= ABS(RAT)
00057      IF( RAT.LE.VAL) RAT=0.0E00
00062      C12S = RAT/ SCY(I)
00064      TS22S = (SG(I+N,1)/SCY(I))**2
00070      60 TO 3
00071      2 VAL = STY(I)* 1.00E-60
00074      RAT = SG(I+2*N,1)*SG(I+N,1)/STY(I)
00102      VAL = ABS(VAL)
00104      RAT = ABS(RAT)
00105      IF(RATE.VAL) RAT=0.0E00
00110      C12S=RAT/STY(I)
00112      TS22S = (SG(I+N,1)/STY(I))**2
00116      3 S125 = T12S + TS22S
00120      IF( ABS(S125)*LT.1.00E-20) 60 TO 40
00123      PN12 = S12S**((XM-1.)/2.)
00132      PN32 = S12S**((XM-3.)/2.)
00141      PM12 = S12S**((XM-1.)/2.)
00150      PM32 = S12S**((XM-3.)/2.)
00157      GO TO 80
00160      40 CONTINUE
00160      PN12 = 0.
00161      PN32 = 0.
00162      PM12 = 0.
00163      PM32 = 0.
00164      80 CONTINUE
00164      C      SNS = SINS(I)
00166      CSS = COS2(I)

```

```

00167      SN2   = SIN2(I)
00171      CS2   = COS2(I)
C
00172      F(1,I) = S11(I)*CSS + S21(I)*SNS
00173      F(2,I) = S12(I)*CSS + SNS/F22(I) + SNS/E22(I)*PN12
00174      1       + SNS*T22S*(XN-1)*E22(I)*PN32
00175      2       - SN2*(XM-1)/(2.*G12(I))*PM32*C12S
00176      F(3,I) = - SN2/(2.*G12(I)) - SN2/(2.*G12(I))*PM12
00177      1       - SN2*T12S*(XM-1)/(2.*G12(I))*PM32
00178      2       + C12*(XN-1)/E22(I)*PN32
00179      G(1,I) = S11(I)*SNS + S21(I)*CSS
00180      G(2,I) = SNS*S12(I) + CSS/F22(I) + PN12*CSS/E22(I)
00181      1       + CSS*(XN-1)*PN32/TS22S
00182      2       + (XM-1)*C12S*SN2*PM32/(2.*G12(I))
00183      G(3,I) = SN2/(2.*G12(I)) + SN2*PM12/(2.*G12(I))
00184      1       + SN2*(XM-1)/(2.*G12(I))*PM32*T12S
00185      2       + (XN-1)*C12TPN32*CSS/E22(I)
00186      H(1,I) = (S1(I)-S21(I))*SN2/C.
00187      H(2,I) = S12(I)*SN2/C. - SN2/(2.*E22(I)) - PN12*SN2
00188      1       /(2.*E22(I)) - (XN-1)*PN32*SN2/(2.*E22(I))
00189      2       *TS22S
00190      3       *CSS/(2.*G12(I))
00191      H(3,I) = CS2/(2.*G12(I)) + PM12*CS2/(2.*G12(I))
00192      1       + (XM-1)*PM32
00193      2       - (XN-1)*C12T*PN32
00194      RETURN
C
00422      END

```

```

      C          SUBROUTINE RESET(LT3,SG,RVAL)
      C          ROUTINE RESET SETS RELATIVE SMALL STRESS TERMS EQUAL TO ZERO,
      C          TO AVOID CONVERGENCE DIFFICULTIES (I.E., VALUES ) RVAL,
      C
      C          DIMENSION      SG(LT3,1)
      C          FIND MAXIMUM STRESS VALUE
      SGMX = ABS(SG(1,1))
      DO 318 K=2,LT3
      IF( ABS(SG(K,1)) .GT. SGMX) SGMX = ABS(SG(K,1))
      318 CONTINUE
      C          COMPARE EACH RELATIVE STRESS VALUE TO RVAL
      DO 319 K=1,LT3
      RAT = ABS(SG(K,1)/SGMX)
      IF(RAT.LT.RVAL) SG(K,1) = 0.0E 00
      319 CONTINUE
      RETURN
      END
      J00006
      J00010
      J00011
      J00025
      J00030
      J00031
      J00037
      J00046
      J00051
      J00051

```

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```

      C SURROUNTING CONVR(LAY,SG,S61,KSG,IRTN)
      C ROUTINE CONVR CHECKS FOR CONVERGED SOLUTION DURING NEWTON-RAPHSON
      C ANALYSIS. ALSO CHECKS ITERATION LIMIT AND DIVERGENCE LIMIT.
      C
      C DIMENSION SG(60,1),SG1(60,1)*DIF(60)
      C COMMON /SET11/ EPS,UPRD,NIT,IT,SMLT
      C
      000010          TCON = 1
      000011          N = LAY
      000012          LT3 = LAY*3
      000013          IRTN=1
      C
      C CONVERGENCE CHECK
      000014          DO 375 J3=1,LT3
      000015          SUR = ABS(SG(J3,1))-ABS(SG1(J3,1))
      000016          IF (SG1(J3,1)*EQ.0.0E0) GO TO 330
      000017          DIF (J3) = ABS(SUB/SG1(J3,1))
      000018          GO TO 335
      000019          330 CONTINUE
      000020          DIF(J3) = SUR
      000021          335 CONTINUE
      000022          IF (DIF(J3)*GT.EPS) GO TO 340
      000023          GO TO 375
      C
      C ITERATION CHECK
      000040          340 CONTINUE
      000041          IF ((NIT-IT)*NE.0) GO TO 350
      000042          ICON = 3
      000043          IF (DIF (J3)*LE.*UPRD) GO TO 375
      000044          TCON = 4
      000045          GO TO 375
      C
      C DIVERGENCE CHECK
      000050          350 IF (DIF (J3)*LE.*UPRD) GO TO 370
      000051          ICON = 4
      000052          GO TO 375
      C
      C 370 CONTINUE
      000053          TCON = 2
      000054          375 CONTINUE
      C
      000061          GO TO (570,400,382,386)*ICON
      C
      C NON-CONVERGENCE DUMP
      000071          382 CONTINUE
      000072          WRITE(6,1720)
      000073          WRITE(6,1722) EPS
      000103          GO TO 395
      000107          386 CONTINUE
      000108          WRITE(6,1730)
      000113          WRITE(6,1722) UPRD
      000121          395 CONTINUE

```

RUN VERSION 2.3 --PSR LEVEL 363--

CONVR

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```

000121      NITP = NIT = 1
000123      WRITE(6,174) NIT,NITP
000133      WRITE(6,1742)
000137      DO 397 I=1,LAY
000144      WRITE(6,1550) 1*SG(I,1),SG(I+N,1),SG1(I,1),SG1(I+N,1),
1                         SG1(I+2*N,1),DIF(I+N),DIF(I+2*N)
000241      397 CONTINUE
000247      IRTN=3
000250      RETURN
000250      400 IRTN=2
000251      500 RETURN
C
C   1550 FORMAT (14,1X,2(3E13.5,4X),3E13.5)
000252      1550 FORMAT (* SOLUTION FOR STRESS DOES NOT CONVERGE*)
000252      1720 FORMAT (* SOLUTION FOR STRESS *GT*.*E15.5)
000252      1722 FORMAT (* RELATIVE ERROR *GT*.*E15.5)
000252      1730 FORMAT (* SOLUTION FOR STRESS DIVERGES*)
000252      1741 FORMAT (* SOLUTION FOR STRESS DIVERGES*)
000252      1741 FORMAT (/18X*,*ITERATION *,I3,*)*,28A,*(*ITERATION *,I3,*)*)
000252      1742 FORMAT (* LAYER*,*4X,*SGM X*,8X,*SGM Y*,8X,*SGM XY*,11X,*SGM X*,8X,
1                         AX,*SGM Y*,8X,*SGM XY*,11X,*REL X*,8X,*REL Y*,8X,
2                         *REL XY*/)
000252      END

```

```

SUBROUTINE LAMTST(LAY,SG,SGS,EPN,PS,KSG,KSGM,IFCN,UFAIL,FAC,SW)
C ROUTINE LAMTST PERFORMS FAILURE ANALYSIS, STIFFNESS TEST, ULTIMATE
C STRESS, ULTIMATE STRAIN, AND QUADRATIC INTERACTION
C
C * VARIABLE DICTIONARY *
C
C UFAIL(I)      : INDICATE FAILURE UNDER SEPARATE MODES
C IFCN          : FOR MULTI-MODE FAILURE ANALYSIS (I.E., IFCN=4)
C LFAIL         : FAILURE MODE
C IJJ           : FAILURE MODE
C KJJ           : ORIENTATION OF STRESS FAILURE
C QIT(I)        : ORIENTATION OF STRAIN FAILURE
C QPV(I)        : QUADRATIC INTERACTION TERM FOR LAYER I
C FAC           : QUADRATIC INTERACTION TERM FOR LAYER I
C IST            : PROV LOAD
C TSV            : INTERPOLATION FACTOR
C KSV            : STORE LAYER NO. AT FAILURE
C                 : STORE STRESS ORIENTATION NO. AT FAILURE
C                 : STORE STRAIN ORIENTATION NO. AT FAILURE
C
C *****
C
C 000016        SG(60,1)*SGS(60)
C 000016        EPS11(20)*FPS22(20)*EPS12(20)
C 000016        P11(20)*P22(20),P12(20),
C 1              ULT(6,2),ULTMA(6,2,20),
C 1              EP11(20),EP22(20),EP12(20)
C 1              QIT(20)*QPV(20)
C 000016        A11(20)*A22(20),A44(20),A12(20)*B1(20)*B2(20)
C 000016        EPN(60,1)*PS(60)
C 000016        UFAIL(3)*Sw,T
C
C COMMON /SET03/EP11,EP22,EP12
C COMMON /SET04/ S011,S022,S012,S012,SM11,SM22,SM12
C COMMON /SET05/ ULTIMA,STIFF
C COMMON /SET07/EP511,EP522,EP512
C COMMON /SET14/ A11,A22,A44,A12,B1,B2
C
C EVALUATE QUADRATIC INTERACTION COEFFICIENTS IF QUAD. INTER. FAILURE
C IF ((IFCN.EQ.3).OR.(IFCN.EQ.4)) CALL QUADCF(LAY)
C
C 000016        IST = 1
C 000032        LFAIL = 0
C 000033        YPT = 1
C 000034        T = 1
C
C 500 CONTINUE
C 000035        NO 475 J=IST,1,AY
C 000036        NO 550 T=1,6
C 000037        NO 550 T=1,6
C 000040        NO 550 J=1,2
C 000042        MLT(I,I,J,J) = ULTIMA(I,I,J,J,1)
C 000043
C 550 CONTINUE
C
C TEST 1: STIFFNESS TEST

```

```

000056      IF (KSG,FQ,1) GO TO 560
000060      IF (501,FQ,0,E0) GO TO 560
000061      RATIO = ABS(SM1)/(EP1(I)-FPS1(I))
000065      IF (RATIO.LT.STIFF) GO TO 677
          TEST 2: ULTIMATE STRESS
          C      ULT(1,1); MAX. AXIAL TENS.
          C      ULT(2,1); MAX. TRAN. TENS.
          C      ULT(3,1); MAX. SHEAR
          560  CONTINUE
          000070      IF ((NOT.((IFCN.EQ.1).OR.(IFCN.EQ.4))) GO TO 570
          000071      IF ((UFAT1(I).EQ.1).AND.(IFCN.EQ.4)) GO TO 570
          IJJ=1
          IF (SG(I,1)=0.0) 1,1,2
          1  TF ( ABS(SG(I,1))-ULT(1,2))3,679,679
          2  IF ( SG(I,1) -ULT(I,1))3,679,679
          3  K= I+LAY
          000126      IJJ=2
          000127      IF (SG(K,1)=0.0)4,4,5
          4  IF ( ABS(SG(K,1))-ULT(2,2))6,679,679
          5  IF (SG(K,1) -ULT(2,1))6,679,679
          6  K= I+2*LAY
          IJJ=3
          IF ( ABS(SG(K,1))-ULT(3,1))570,679,679
          C      TEST 3: ULTIMATE STRAIN
          C      ULT(4,1); MAX. AXIAL TENS.
          C      ULT(5,1); MAX. TRAN. TENS.
          C      ULT(6,1); MAX. SHEAR
          570  CONTINUE
          IF ((NOT.((IFCN.EQ.2).OR.(IFCN.EQ.4))) GO TO 580
          TF ((UFAT1(2).EQ.1).AND.(IFCN.EQ.4)) GO TO 580
          KJJ = 1
          000153      TF (EPNT1,I)-0.0) 71,71,72
          000163      71  IF ( ABS(EPN(I,1))-ULT(4,2))73,689,689
          000174      72  IF ( EPN(I,1)-ULT(4,1))73,689,689
          000204      73  CONTINUE
          000210      K = I+LAY
          000212      KJJ = 2
          000213      IF (EPN(K,1)=0.0) 74,74,75
          000216      74  IF ( ABS(EPN(K,1))-ULT(5,2))76,689,689
          000223      75  IF (EPN(K,1)-ULT(5,1))76,689,689
          000227      76  CONTINUE
          K = I+2*LAY
          KJJ = 3
          IF ( ABS(EPN(K,1))-ULT(6,1))580,689,689
          C      TEST 4: QUADRATIC INTERACTION
          000237      580  CONTINUE
          000231      IF ((NOT.((IFCN.EQ.3).OR.(IFCN.EQ.4))) GO TO 590
          000247      TF ((UFAT1,(3).EQ.1).AND.(IFCN.EQ.4)) GO TO 675
          000257      QIT(I) = A1(I)*SG(I,1)**2 + A2(I)**SG(I+LAY,1)**2
          1           + A4(I)*SG(I+2*LAY,1)**2 + A12(I)*SG(I,1)*SG(I+1)
          2           + H1(I)*SG(I,1) + H2(I)*SG(I,1)*SG(I+LAY,1)
          TF (    QIT(I) *67,1,0) GO TO 699
          000312

```

```

92      C 590 CONTINUE
000316  C
000326  675 CONTINUE
000321  IF (LFAIL•NE•0) GO TO A10
000322  WRITE (6,1995)
000325  RETURN

C   SET INDICATOR OF FAILURE MODE
000326  677 LFAIL = 1
000327  KSGM = KSGM
000328  GO TO 700
000329  679 LFAIL = 2
000330  TST = T
000331  GO TO 700
000332  680 LFAIL = 3
000333  TST = T
000334  GO TO 700
000335  681 LFAIL = 4
000336  TST = T
000337  GO TO 700
000338  682 LFAIL = 5
000339  TST = T
000340  GO TO 700
000341  683 LFAIL = 6
000342  TST = T
000343  GO TO 700
000344  684 LFAIL = 7
000345  TST = T
000346  GO TO 700
000347  685 LFAIL = 8
000348  TST = T
000349  GO TO 700
000350  686 LFAIL = 9
000351  TST = T
000352  GO TO 700
000353  687 LFAIL = 10
000354  TST = T
000355  GO TO 700
000356  688 LFAIL = 11
000357  TST = T
000358  GO TO 700
000359  689 LFAIL = 12
000360  TST = T
000361  GO TO 700
000362  690 LFAIL = 13
000363  TST = T
000364  GO TO 700
000365  691 LFAIL = 14
000366  TST = T
000367  GO TO 700
000368  692 LFAIL = 15
000369  TST = T
000370  GO TO 700
000371  693 LFAIL = 16
000372  TST = T
000373  GO TO 700
000374  694 LFAIL = 17
000375  TST = T
000376  GO TO 700
000377  695 LFAIL = 18
000378  TST = T
000379  GO TO 700
000380  696 LFAIL = 19
000381  TST = T
000382  GO TO 700
000383  697 LFAIL = 20
000384  TST = T
000385  GO TO 700
000386  698 LFAIL = 21
000387  TST = T
000388  GO TO 700
000389  699 LFAIL = 22
000390  TST = T
000391  GO TO 700
000392  700 CONTINUE
000401  IF (IPT•EQ•1) WRITE (6,1990)
000413  IPT = 0
000414  IF (IFCN•NE•4) KSGM=KSGM
000420  GO TO (7n1,703,723,743), LFAIL
000430  701 WRITE (6,1450)
000434  GO TO R50
000440  703 CONTINUE
000441  ISV = IJJ
000442  GO TO (704,705,706)•IJJ
000450  704 WRITE (6•1452)
000454  GO TO 799
000460  705 WRITE (6•1453)
000464  GO TO 799
000470  706 WRITE (6•1454)
000474  GO TO 799
C   723 CONTINUE
000500  KSV = KJJ
000502  GO TO (724,725,726)• KJJ
000510  724 WRITE (6•1462)
000514  GO TO 799
000520  725 WRITE (6•1463)
000524  GO TO 799
000530  726 WRITE (6•1464)
000534  GO TO 799
000540  C 743 WRITE (6,1472) (IJT(T),T,JPV(T),T
000554  C 799 CONTINUE

```

HUN VEPSON 2.3 ==PSR LVEL 363==

LAMTST

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```
000554 IF (IFCN,NE*4) GO TO 850
000562 LFM = LFAIL=1
000564 UFAIL(LFM) = 1
000566 IF ((UFAIL(1)*EQ.1).AND.(UFAIL(2)*EQ.1))
1          KSG = KSGM
000605 GO TO 500
000606 810 CONTINUE
000606 IF (KSG,EQ.1) GO TO 850
000610 SW = 1
000611 IF ( LFAIL.EQ.2 ) FAC = SINT(SG,SGS,ISV,1,IST,LAY)
000624 IF ( LFAIL.EQ.3 ) FAC = SINT(EPNAPS,KSV,2,IST,LAY)
000637 IF ( LFAIL.EQ.4 ) FAC = (1.0-QPV(1ST)) / (QIT(1ST)-QPV(1ST))
000646 850 WRITE(6,1495)
C
000652 1450 FORMAT (/* LAMINATE HAS FAILED* STIFFNESS TEST FAILURE*)
000652 1452 FORMAT (/* LAMINATE HAS FAILED* SG 11 EXCEEDS MAXIMUM*)
000652 1453 FORMAT (/* LAMINATE HAS FAILED* SG 22 EXCEEDS MAXIMUM*)
000652 1454 FORMAT (/* LAMINATE HAS FAILED* SG 12 EXCEEDS MAXIMUM*)
000652 1462 FORMAT (/* LAMINATE HAS FAILED* EP 11 EXCEEDS MAXIMUM*)
000652 1463 FORMAT (/* LAMINATE HAS FAILED* EP 22 EXCEEDS MAXIMUM*)
000652 1464 FORMAT (/* LAMINATE HAS FAILED* EP 12 EXCEEDS MAXIMUM*)
000652 1472 FORMAT (/* LAMINATE HAS FAILED* QUADRATIC INTERACTION*
*      * FAILURE*/ 27X*QUADRATIC = *,F7.4,* FOR LAYER *,12/
*      * 27X*QUADRATIC = *,F7.4,* FOR LAYER *,12,
*      * OF PREVIOUS LOAD*)
000652 1495 FORMAT (/* AT FIRST POST-FAILURE LOAD POINT*)
000652 1990 FORMAT (////)
000652 1995 FORMAT (1H0)
C           RETURN
000652
000653 FND
```

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```

      SUBROUTINE QUADCF(LAY)
C   COMPUTES QUADRATIC FAILURE CRITERIA COEFFICIENTS
C
      DIMENSION          ULTIMA(6,2,20)
      DIMENSION          A11(20),A22(20),A44(20),A12(20),B1(20),B2(20)
      COMMON /SET05/ ULTIMA,STIFF
      COMMON /SET14/ A11,A22,A44,A12,B1,B2
C
      DO 100 IMTALY=1,LAY
      A11(IMTALY) = 3.*ULTIMA(1,1,IMTALY)*ULTIMA(1,2,IMTALY)
      A22(IMTALY) = 1./ULTIMA(2,1,IMTALY)*ULTIMA(2,2,IMTALY)
      A44(IMTALY) = (1.*ULTIMA(3,1,IMTALY))**2
      B1(IMTALY) = 1./ULTIMA(1,1,IMTALY)
      B2(IMTALY) = 1./ULTIMA(2,1,IMTALY) - 1./ULTIMA(1,2,IMTALY)
      B2(IMTALY) = 1.*ULTIMA(2,1,IMTALY) - 1./ULTIMA(2,2,IMTALY)
      100 CONTINUE
C
      RETURN
      END

```

RUN VERSION 2.3 --PSR LFLEVEL 363--

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```
SUBROUTINE LAYSUB (A12,STY,SCY,TY,EPS11,EPS22,EPS12)
  DIMENSION E1(20),E22(20),V12(20),V21(20),G12(20),A12(20),
  1  STY(20),SCY(20),TY(20),EPS11(20),EPS22(20),EPS12(20),
  DIMENSION TE11(20),TE22(20),TG12(20),TV12(20),TSTY(20),
  1
  COMMON /SET01/ E11,E22,V12,V21,G12
  COMMON /SET17/ TE11,TE22,TG12,TV12,TSTY,SCY,TY
  DO 10 I = 1,20
  E11(I) = TE11(I)
  E22(I) = TE22(I)
  G12(I) = TG12(I)
  V12(I) = TV12(I)
  A12(I) = TA12(I)
  STY(I) = TSTY(I)
  SCY(I) = TSCY(I)
  10 TY(I) = TTY(I)
  RETURN
END
```

96 RUN VERSION 2.3 --PSK LEVEL 363--

07/23/74

REAL FUNCTION SINT(VAL,PREV,IO,SINT)

C FUNCTION SUBPROGRAM SINT DETERMINES INTERPOLATION FACTOR FOR
C STRFS OR STRAIN FAILURE

C * VARIABLE DICTIONARY *

C VAL(I+1) : VALUE OF STRESS OR STRAIN AFTER FAILURE
C PREV(I) : VALUE OF STRESS OR STRAIN BEFORE FAILURE
C FLEMT : ELEMENT OF STRESS OR STRAIN ARRAY WHICH HAS FAIL
C SINT : INTERPOLATION FACTOR

C *****

000011 DIMENSION VAL(60,1),PREV(60),ULT(6,2,20)
000011 COMMON /SET05/,ULT,STIFF
000011 INTEGER SS,ELEM

000011 C TF (SS.EQ.1) IOS=IOR
000014 IF (SS.EQ.2) IOS=IOR+3
000020 ELEM = (IOR-1)*N + I

000023 C TSN=2
000024 IF (VAL(FLEMT,1).GT.0.00) TSN=1

000030 C DPRV = ABS(PREV(ELEM))
000033 DDIF = ABS(VAL(ELEM+1)-PREV(ELEM))
000036 SINT = (ULT(IOS,TSN+1)-DPRV)/DDIF

000045 C RETURN
000046 END

```

      BLOCK DATA
      C   BLOCK DATA SUBPROGRAM INITIALIZES VARIABLES
      C   IN COMMON SETS 01,05,10,11,14
      C
      COMMON /SET01/ DUM01(100)
      COMMON /SET05/ ULT(240),STIFF
      COMMON /SET10/ DUM1(62)
      COMMON /SET11/ EPS,UPRD,NIT,IT,SMLT
      COMMON /SET14/ A11,A22,A44,A12,B1,R2
      COMMON /SET15/ POINTS,IPRINT,IOPT,IMTS,LUP
      COMMON /SET16/ A11(20),A22(20),A44(20),B1(20),B2(20)
      DIMENSION POINTS(50,6,20)
      DIMENSION A12(20),B1(20),B2(20)
      DATA A12/20*0.100/
      DATA B1/20*0.0/
      DATA B2/20*0.0/
      DATA EPS/100*0.0/
      DATA ULT/240*0.0/
      DATA DUM1/60*0.00*2*3.00/
      DATA IT/100/
      DATA UPBD/200000./
      DATA IPRINT/0/
      END

```

REFERENCES

- (1) Z. Hashin, D. Bagchi and B. W. Rosen, "Non-Linear Behaviour of Fiber Composite Laminates", NASA CR-2313, 1973.
- (2) Z. Hashin and B. W. Rosen, "the Elastic Moduli of Fiber Reinforced Materials", J. Applied Mechanics, Vol. 31, p. 223, 1964.
- (3) B. W. Rosen and Z. Hashin, "Effective Thermal Expansion Coefficients and Specific Heats of Composite Materials", Int. J. Engineering Science, Vol. 8, p. 157, 1970.